



**US Army Corps
of Engineers**
Jacksonville District

Final Five-Year Review Report

First Five-Year Review Report for MIAMI DRUMS SERVICES Miami, Dade County, Florida,

March 2003

Prepared for
U.S. Environmental Protection Agency, Region IV

Approved by:

Date:

May 2, 2003

EPA Five-Year Review Summary Form

SITE IDENTIFICATION		
Site Name (from WasteLAN): Miami Drum Services Site		
EPA ID (from WasteLAN): FLD076027820		
Region: 4	State: FL	City/County: Miami/Dade
SITE STATUS		
NPL status: <input checked="" type="checkbox"/> Final <input type="checkbox"/> Deleted <input type="checkbox"/> Other (specify)		
Remediation status (choose all that apply): <input type="checkbox"/> Under construction <input type="checkbox"/> Operating <input checked="" type="checkbox"/> Complete		
Multiple OUs? <input type="checkbox"/> YES <input checked="" type="checkbox"/> NO		Construction Completion Date: January 1982
Has site been put into reuse? <input checked="" type="checkbox"/> YES <input type="checkbox"/> NO		
REVIEW STATUS		
Lead agency: <input checked="" type="checkbox"/> EPA <input type="checkbox"/> State <input type="checkbox"/> Tribe <input type="checkbox"/> Other Federal Agency		
Author name: William Neimes		
Author title: Engineer		Author affiliation: U.S. Army Corps of Engineers
Review period: 7/15/02 – 9/30/02		
Date of site inspection: 7/25/02		
Type of review:		
<input type="checkbox"/> Post-SARA <input checked="" type="checkbox"/> Pre-SARA <input type="checkbox"/> NPL-Removal only <input type="checkbox"/> Non-NPL Remedial Action Site <input type="checkbox"/> NPL State/Tribe-lead <input type="checkbox"/> Regional Discretion		
Review number: <input checked="" type="checkbox"/> 1 (first) <input type="checkbox"/> 2 (second) <input type="checkbox"/> 3 (third) <input type="checkbox"/> Other (specify)		
Triggering action:		
<input type="checkbox"/> Actual RA On-site Construction at OU# ____ <input type="checkbox"/> Actual RA Start at OU# ____ <input checked="" type="checkbox"/> Construction Completion <input type="checkbox"/> Previous Five-Year Review Report <input type="checkbox"/> Other (specify)		
Triggering action date (from WasteLAN): 9/30/02		
Due date (five years after triggering action date): 9/30/07		

Issues:

Miami Dade Water and Sewer Department to continue annual monitoring of water supply wells and provide an annual summary report on the reduction of VOC's associated with treatment remedy.

Miami Dade Water and Sewer Department to evaluate whether reduction in VOC's is through the Biscayne Aquifer Remedy or whether other natural phenomena are assisting in VOC reduction (i.e., biodegradation).

Miami Dade Water and Sewer Department to consider the volatilization of VOC's through conventional water treatment plant in addition to calculations being performed for the air strippers.

Miami Dade County to update local repository with applicable reports.

Upon site closure, a restrictive covenant will be required to ensure that the surface seal is maintained.

Recommendations and Follow-up Actions:

EPA to receive reports noting supply well VOC concentrations.

Add monitoring of biodegradation parameters for chlorinated ethenes. The list of parameters is provided in Attachment E.

Miami Dade County to review records in local repository and update records accordingly.

Protectiveness Statement(s):

Based upon records in the FDEP files in Tallahassee, Florida, the selected remedy, as executed, appears to remain protective of human health and the environment. Continued groundwater monitoring at each municipal supply well, the water treatment plant influent and effluent should be performed and documented to ensure long-term protectiveness.

Long-Term Protectiveness:

Long-term protectiveness of the remedial action for the Miami Drum Services Site is maintained by continued operation of the Dade County Transit Maintenance and Repair Facility. Long-term protectiveness of the remedial action for the groundwater contaminant plume is through continued monitoring of municipal supply wells and continued treatment of the groundwater at both the John E. Preston and Hialeah Water Treatment Plants.

Other Comments:

None.

**Miami Drum Services
Miami, Dade County, Florida
Superfund Five-Year Review Report**

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List of Acronyms

ARAR	Applicable, or Relevant and Appropriate Requirements
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
COC	Contaminant of Concern
DCDH	Dade County Department of Health
DERM	Dade County Environmental Resource Management
DEQ	Dade County of Environmental Quality
EPA	Environmental Protection Agency
ESD	Explanation of Significant Differences
FAC	Florida Administrative Code
FEC	Florida East Coast Railway
FDEP	Florida Department of Environmental Protection
FDER	Florida Department of Environmental Regulation
FS	Feasibility Study
GPM	Gallon per Minute
MCL	Maximum Contaminant Limit
MDWSD	Miami Dade Water and Sewer Department
MGD	Million Gallon per Day
NGVD	National Geodetic Vertical Datum
RA	Remedial Action
RD	Remedial Design
RI	Remedial Investigation
ROD	Record of Decision
TOC	Total Organic Carbon
THM	Trihalomethane
USACE	United States Army Corps of Engineers
VOC	Volatile Organic Compound
WTP	Water Treatment Plant

Executive Summary

Miami Drums Services was a drum recycling facility located west of Miami Springs at 7049 N.W. 70th Street in Miami. The site was in operation for 15 years between 1966 and 1981. The Miami Drums Services site is one of three sites located in northwest Dade County, Florida that was proposed for the National Priorities List in October 1981. The other two sites being the Varsol Spill and the 58th Street Landfill. The EPA decided to address the Miami Drums site and the other two sites as a single management unit for the performance of the RI/FS.

The result of the Miami Drums investigation as well as the Varsol Spill and 58th Street Landfill investigations indicated that, there was no concentrated contaminant plume emanating from the Miami Drums site nor the other two Superfund sites to the well fields. However, low, dispersed levels of volatile organic chemicals have been found throughout the study area and groundwater plumes have blended together and become indistinguishable with the general poor groundwater quality in the developed area.

The Remedial Action took place in two separate phases. The first phase entailed the removal and off-site disposal of hazardous waste soils and debris and the treatment of contaminated groundwater associated with the Miami Drums Site. The activities for this phase were initiated in December 1981 and were completed in January 1982.

The second phase entailed recovering and treating the contaminated groundwater. Although a separate and distinct plume has not been identified to this site, the Biscayne Aquifer Remedial Investigation found that continuous pumping of the Miami Springs and Preston production wells tends to draw associated groundwater contaminants from the former Miami Drums Services Site. Therefore, it was determined that withdrawal and treatment of groundwater at a centralized location (i.e., Preston and Hialeah WTP's) was more favorable than treatment of groundwater at the different sources. 44 and 20 air strippers were added to the Preston and Hialeah WTP's, respectively in 1992 to treat the volatile organic constituents associated with the Miami Drums site and other NPL sites.

The Miami-Dade Water and Sewer Department have been monitoring VOC contamination in the Hialeah Well field, the Upper and Lower Miami Springs Well field and the John E. Preston Well field quarterly from 1988 to 1992 and annually from 1993 to present.

Based upon records in the FDEP files in Tallahassee, Florida, the selected remedy, as executed, appears to remain protective of human health and the environment. Long-term protectiveness of the remedial action for the Miami Drum Services Site is maintained by continued operation of the Dade County Transit Maintenance and Repair Facility. Long-term protectiveness of the remedial action for the groundwater contaminant plume is through continued monitoring of municipal supply wells and continued treatment of the groundwater at both Water Treatment Plants.

Miami Drum Services Miami, Dade County, Florida Superfund Five-Year Review Report

I. Introduction and Purpose

The purpose of the five-year review is to determine whether the remedy at a site is protective of human health and the environment. The methods, findings, and conclusions of reviews are documented in Five-Year Review Reports. In addition, Five-Year Review reports identify issues found during the review, if any, and identify recommendations to address them.

The Agency is preparing this Five-Year Review report pursuant to CERCLA § 121 and the National Contingency Plan (NCP). CERCLA § 121 states:

If the President selects a remedial action that results in any hazardous substances, pollutants, or contaminants remaining at the site, the President shall review such remedial action no less often than each five years after the initiation of such remedial action to assure that human health and the environment are being protected by the remedial action being implemented. In addition, if upon such review it is the judgment of the President that action is appropriate at such site in accordance with section (104) or (106), the President shall take or require such action. The President shall report to the Congress a list of facilities for which such review is required, the results of all such reviews, and any actions taken as a result of such reviews.

The Agency interpreted this requirement further in the NCP; 40 CFR §300.430(f)(4)(ii) states:

If a remedial action is selected that results in hazardous substances, pollutants, or contaminants remaining at the site above levels for unlimited and unrestricted exposure, the lead agency shall review such action no less than every five years after the initiation of the selected remedial action.

The United States Army Corps of Engineers, Jacksonville District (USACE), on behalf of the United States Environmental Protection Agency (EPA), Region IV, conducted the five-year review of the remedy implemented at the Miami Drums Superfund Site in Miami, Florida. This review was conducted by the by the USACE project engineer for the site from July 2002 through August 2002. This report documents the results of the review.

This is the first five-year review for the Miami Drums Superfund Site. The five-year

review is required due to the fact that hazardous substances, pollutants, or contaminants remain at the site above levels that allow for unlimited use and unrestricted exposure.

II. Site Chronology

Table 1 - Chronology of Site Events

Event	Date
Miami Drums Services Site	
Discovery of Contamination at Miami Drums Services	11/01/79
Excavation of Materials and Soils from Miami Drums Services	12/81-1/82
EPA Region IV concurrence with removal actions at Miami Drums Services	8/26/82
FDER acceptance of removal actions at Miami Drums Services	9/1/82
Miami Drums Services Record of Decision	09/13/82
Biscayne Aquifer Sites	
Phase I Report - Protection of Biscayne Aquifer	10/15/82
Dade County Well field Protection Ordinance adopted by County	09/06/83
Final Listing on National Priorities List for Biscayne Aquifer	09/08/83
Phase II Report - Protection of Biscayne Aquifer	2/84
Phase III Report - Protection of Biscayne Aquifer	5/85
Biscayne Aquifer Record of Decision	9/16/85
Biscayne Aquifer Remedial Design	9/30/87
Cooperative Agreement Executed by EPA	9/30/88
Biscayne Aquifer Remedial Action	9/88 - 6/93
Biscayne Aquifer Removal Assessment	8/25/92
Initiation of Operation of all Air Stripping Towers	9/1/92
Other Associated Sites	
Varsol Spill Site Record of Decision	3/29/85
58 th Street Landfill Record of Decision	9/21/87

III. Background

General

The Miami Drums Services site is one of three sites located in northwest Dade County, Florida that was proposed for the National Priorities List in October 1981. The other two sites being the Varsol Spill and the 58th Street Landfill. The EPA decided to

address the Miami Drums site and the other two sites as a single management unit for the performance of the RI/FS. A major reason for this decision was that all three sites affect the same general area of the Biscayne Aquifer. The EPA, state and local agencies recognized that the effects of these sites on the aquifer could be interrelated and that some of the suspected problems would not be solely attributable to an individual site.

A package of four decision documents addresses these three sites. These documents include:

Varsol Spill Site – Record of Decision signed 3/29/85

Miami Drum Services Site– Record of Decision signed 9/13/82

58th Street Landfill Site– Record of Decision signed 9/21/87

Biscayne Aquifer Sites – Record of Decision signed 9/16/85

Site Location and Description

The Biscayne Aquifer is the sole underground source of drinking water for the residents of southeast Florida. Three Biscayne Aquifer hazardous waste sites on the EPA National Priorities List were addressed as one management unit for the remedial investigation and feasibility study: (1) Miami Drum Site, (2) Northwest 58th Street Landfill, and (3) Varsol Spill Site (Miami International Airport). These sites are located near each other in north Dade County, Florida. The study area including these sites is shown in Figure 1. The Biscayne Aquifer study area encompasses approximately 80 square miles.

Miami Drums Services Site

Miami Drums Services was a drum recycling facility located west of Miami Springs at 7049 N.W. 70th Street in Miami. The site was in operation for 15 years between 1966 and 1981. The dimensions of this site are 242 feet by 230 feet (approximately 1.3 acres) and it was located in a predominantly industrial area. The Florida East Coast Canal and the Florida East Coast Railroad right-of-way are located about one quarter of a mile east of the Miami Drum Site. The Miami Canal is located less than one mile northeast of the site. The Medley Well Field is located approximately 750 feet west of this site, while the Miami Springs and Preston Well Fields are generally located within a mile southeast of the site. The nearest well in the Miami Springs/Preston Well Field to the Miami Drum Services site is Miami Springs Well No. 9. This well is located on the east side of the Florida East Coast Canal, approximately a half of a mile southeast from the Miami Drum Services site.

The area surrounding the former Miami Drum Services Superfund site includes several cities as well as unincorporated areas. The cities of Miami Springs and Virginia Gardens are primarily residential, whereas the cities of Medley and Hialeah Gardens are heavily industrial. The City of Hialeah is a mix of residential, commercial and industrial areas.

Northwest 58th Street Landfill Site

The Northwest 58th Street Landfill occupies a one-square-mile area near the western perimeters of the Town of Medley and the City of Miami Springs. The Miami Springs/Preston Well Field is approximately two and one-half miles east from the eastern edge of the landfill.

Varsol Spill Site

The Varsol Spill Site is located in the northeast section of the Miami International Airport (MIA). The airport is located less than one-half mile south of the lower Miami Springs Well Field. The Miami Canal runs adjacent to the northeast corner of the airport, the Tamiami Canal runs immediately south of the airport, and two other canals area located near the western edge of the airport.

Hydrogeology

The Biscayne Aquifer underlies the Miami Drums site. This aquifer is designated as a "sole source aquifer" under the Safe Drinking Water Act of 1974 and is composed of four major geologic units: the Miami Oolite, Anastasia Formation, Key Largo Formation, and the Fort Thompson Formation. Figure 2 shows a general geologic cross-section near the site. As noted on this figure, the geology is composed chiefly of limestone and quartz sand. The water producing zones of the Biscayne Aquifer are overlain by the Pamlico Sand which outcrops at the surface of the site. The groundwater hydrology in the site vicinity is controlled mainly by the porosity and permeability of the geologic units. The Pamlico Sand is very permeable so that rainfall readily infiltrates to the water table which is approximately three feet below the surface. The Miami Oolite is also very permeable and commonly contains vertical solution channels which allows the rapid recharge of lower units. The quartz sand which fills some cavities in localized areas may reduce the permeability somewhat. The lower units, especially the Fort Thompson Formation, are cavernous and large diameter wells completed in these formations may produce several thousand gallons of water per minute with very little water level drawdown. Near the site, the range of transmissivities is between 95,000 ft²/day to 430,000 ft²/day.

Another important factor controlling the groundwater hydrology is the infiltration of surface water from nearby canals. The Miami Canal, northeast of the site, reportedly contributes as much as 46 percent of the total pumpage of the Miami Springs-Hialeah well field area. In addition, the rapid response of groundwater levels to canal water controls are evidence of an effective hydraulic connection between the canals and the Biscayne Aquifer.

Groundwater flow in the Biscayne Aquifer is locally regulated by pumpage and canal

flow controls. The canal flow controls are used for flood prevention and salt-water intrusion control. During rainy periods the control structures are opened to allow excess surface water to be discharged to the sea. Opening of the controls results in lower canal water levels and therefore promotes groundwater infiltration into the canal. During dry periods the control structures are closed to capture surface water. Closing of the control structures results in higher canal water levels and therefore promotes surface water infiltration into the Biscayne Aquifer. This recharge aids in the control of salt-water intrusion from the coastal areas.

Site History

The privately owned Miami Drum Services (Miami Drums) facility operated for approximately 15 years before Dade County, through a local court order, forced it to cease operation in April 1981. As many as 5,000 drums of various chemical waste materials, including corrosives, solvents, phenols, and toxic metals, were observed on the site while the company was operating. Drums were washed with a caustic cleaning solution which, along with drum residues containing industrial solvents, acids, and heavy metals, were disposed of onsite in open, unlined pits. An area photograph of the Miami Drums Services Site is shown in Figure 3. This area photograph was taken on January 13, 1981, prior to any remedial activities.

The abandoned Miami Drum Site was acquired by Dade County through eminent domain proceedings for construction of the Palmetto Yard maintenance facility of the Dade County Rapid Rail Transit Project. The site was in the northwest quadrant of the 84-acre yard and shop area for the rapid rail system. In November 1981, the County initiated actions to obtain a cleanup contractor for the site. During this time, the State and EPA began negotiations for a cooperative agreement for the site surface cleanup and a groundwater feasibility study. Concurrently, the State and County began developing a contract for site surface cleanup. Extensive soil borings were performed at the site from December 2 to 7, 1981 and cores up to 10 feet deep were analyzed for contaminants. During this time the above ground structures, drums, and debris were cleared from the site. Between December 8 and 21, 1981, excavation of the north 160 feet of the property (north cell) to a depth of 2.5 feet was accomplished. Approximately 150,000 gallons of associated groundwater (water from the excavation) were treated and recharged to the Biscayne Aquifer. The excavation of the south portion of the property and treatment of 500,000 gallons of associated groundwater was done during the period December 24, 1981 to January 4, 1982. Completion of treatment and on-site disposal of the remaining water from excavation, final cleanup of the site, and demobilization occurred during January 5 to 8, 1982. During January 9 to 15, 1982, the excavated areas were backfilled with clean fill materials. Dade County contracted with O.H. Materials Company to remove the 400 to 500 existing drums from the site, excavate contaminated soils based on the core analyses, and relocate these soils to an existing, approved disposal facility. Simultaneously, EPA completed a feasibility study that addressed the contaminated surface material at the site. This study recommended

excavation and off-site disposal of the contaminated soils. Although the project had not officially been approved for CERCLA funding, the County requested and complied with EPA and State guidance as the cleanup proceeded. A total of 15,000 tons contaminated soil and debris was excavated from the Miami Drums Site. This material was placed in visquene lined trucks and transported to a hazardous waste disposal facility in Emelle, Alabama. This removal activity was jointly funded by the EPA and Dade County. In addition to this action, the contaminated water encountered during excavation was removed, treated, and disposed of onsite. A total of 650,000 gallons of groundwater was treated prior to discharge to the Biscayne Aquifer. At the present time, the maintenance facility of the Dade County Rapid Rail Transit system is operating at this site.

In late 1981, the Florida Department of Environmental Regulation (FDER) contracted with Technos, Inc. to determine the extent of groundwater pollution at the Miami Drums Site. Geophysical measurements using electromagnetics (EM) and ground penetrating radar (GPR) provided the data for this study. The EM results showed a significant conductivity anomaly coincident with the site that provided evidence of a strong plume-like trend to the southeast in the direction of the groundwater flow and towards the Miami Springs/Preston Well Fields. Several less significant conductivity lobes were also detected west and north of the site toward the Medley Well Field. Although the Miami Drums Site significantly contributed to the area wide groundwater problem, this Remedial Investigation, as well as a separate remedial investigation, conducted during 1983 by FDER at the Miami Drum Site, found no evidence of an independent, concentrated contaminant plume from the Miami Drum Site.

The result of the Miami Drums investigation as well as the Varsol Spill and 58th Street Landfill investigations indicted that, there was no concentrated contaminant plume emanating from the Miami Drums site nor the other two Superfund sites to the well fields. However, low, dispersed levels of volatile organic chemicals have been found throughout the study area and groundwater plumes have blended together and become indistinguishable with the general poor groundwater quality in the developed area. The main explanation for this is found in the hydrogeologic conditions within the study area: the high transmissivity of the Biscayne Aquifer; the widespread interaction of groundwater with surface water bodies throughout the study area; and the high, continuous pumping of groundwater at several municipal well fields.

Basis for Taking Action

In 1981, the courts ordered Miami Drum Services to shut down operations because the company violated its operating permits. Since the property was located near existing rail lines, Dade County acquired the land for a maintenance facility and repair yard. Not long after construction started, county transportation officials discovered hazardous waste contamination left behind by Miami Drums.

IV. Remedial Actions

Remedy Selection

Miami Drums Services ROD

Four remedial alternatives were considered for the remedial action of contaminated soils at the Miami Drums Services ROD. Of these four alternatives, offsite removal and disposal was selected as the remedy. EPA used the local expertise of the Dade County Department of Environmental Quality (DEQ) to develop the cleanup strategy for the site. Using funds originally earmarked for transportation projects, DEQ removed the contaminated soil and began treating the groundwater. EPA reimbursed Dade County for its expenses with funds that the Agency had collected from Miami Drum Services and more than 160 other parties that had contributed to the contamination at the site. The cleanup decision of the 1982 ROD included the removal and proper disposal of approximately 15,000 tons of contaminated soil, and the treatment of approximately 650,000 gallons of contaminated groundwater directly beneath the Site.

After the contaminated soil was removed and the cleanup of the aquifer began, Dade County was able to resume the construction of the rail maintenance and repair facility. Now in operation, the 82-acre William Lehman Operations and Maintenance Center serves as a major train repair facility for Dade County's aboveground electric rail system. The facility supports an environmentally friendly means of public transportation by providing the maintenance required for reliable daily operations.

Biscayne Aquifer ROD

The ROD for the Biscayne Aquifer selected Alternative No. 2 as the appropriate remedial action for the study area groundwater. This alternative utilized the existing Miami Springs and Preston Well Fields for contaminant recovery and treats the volatile organic constituents in the recovered groundwater through the use of air strippers at each water treatment plant. The cone of influence from these two well fields covers the Miami Drums site and a large portion of the regional VOC plume.

The Miami Dade Water and Sewer Department (MDWSD) has constructed a treatment system that will handle the combined capacity of the Preston and Hialeah WTPs. This system includes the blending for uncontaminated water from the Northwest well field with the contaminated water from the Miami Springs and Preston Well Fields.

MDWSD's motive for treating the finished water (as opposed to the raw water) from the WTPs was to reduce the level of trihalomethanes (resulting mainly from chlorination of the water at the WTPs) and color in water. The additional treatment for this purpose is unrelated to the hazardous waste contamination of the groundwater in the study area, and thus the added costs would not be eligible for federal participation. The

recommended remedial action of Alternative No. 2 compares favorably with MDWSD's plans because it essentially reduces the VOC contaminants to similar levels as treating the raw water (influent).

An important aspect of the Biscayne Aquifer remedial alternative is related to the operation of the Miami-Dade Water and Sewer Department's water facilities. Included in the following section is a brief summary of the water treatment plants and some of the well fields serving the Dade County residents.

Miami-Dade Water and Sewer Department (MDWSD) Water Facilities

Water supply for MDWSD is derived primarily from seven major wellfields located in the Hialeah-Preston and Alexander Orr Services Areas. Figure 4 depicts wellfield locations within each of the service areas. Treatment of the water from the seven major wellfields is achieved at the three major WTPs: Hialeah, John E. Preston, and Alexander Orr, Jr. The Hialeah and John E. Preston WTPs together treat water from the Northwest, Miami Springs, and Hialeah Wellfields. Alexander Orr, Jr. WTP treats water from the Alexander Orr, Snapper Creek, Southwest, and West Wellfields. All three WTPs use conventional lime softening, followed by filtration and disinfection. The Hialeah and John E. Preston WTPs also use air stripping to treat any VOC contamination known to be present in the Miami Springs and Preston Well field. Figure 4 also shows the physical location of MDWSD's WTPs.

All of MDWSD's water supply wells are constructed into the Biscayne Aquifer, and the water yield ranges from 500 gpm to more than 7,000 gpm per well (Fish and Stewart, 1991). The aquifer is recharged locally by rainwater that percolates downward from the surface as well as by the Everglades, and a system of canals that extend west.

The Hialeah and Preston WTP are supplied water through four water supply wellfields:

- Hialeah Well field (3 active wells)
- Miami Springs (Upper and Lower) (20 active wells)
- Northwest Well field (15 active wells)
- John E. Preston Well field (7 active wells)

Hialeah Well field

The three active wells in the Hialeah Well field were constructed in 1936. The wells are 14-inch diameter and between 80 to 90 feet deep. The capacity of each of the three wells is 2,500 gallons per minute, with a total of 10.8 mgd. These wells are identified as Site 40 on Figure 5 and Table 1.

Miami Springs Well field

There are 20 active wells in the Miami Springs Well field, which is divided into the

Lower Well field (eight wells) and the Upper Well field (12 wells). The wells were constructed between 1924 and 1945, are 14-inch diameter, varies in depth between 49 feet and 146 feet. The design installed capacity of the wells ranges from 2,500 to 5,000 gpm, with a total of 79.4 mgd. The Lower Well field is identified as Site 42 on Figure 5 and Table 1 and includes wells 1-8. The Upper Well field is identified as Site 41 on Figure 5 and Table1 and includes wells 9, 10, and 14 through 23.

Northwest Well field

The 15 active wells in the Northwest Well field were constructed in 1980. The wells are 42-inch diameter and 80 feet deep with 34 feet of casing. The design installed capacity of the wells range from 8,000 gpm to 10,000 gpm. The total design installed capacity for the Northwest Well field is 213.3 mgd. These wells are identified as Site 45 on Figure 5 and Table 1.

John E. Preston Well field

The seven active wells in the John E. Preston Well field were constructed between 1966 and 1972. These wells are 42-inch-diameter and 107 feet deep, with 66 feet of casing in each. The capacity of each well is 7,000 gpm with a total of 70.6 mgd. These wells are identified as Site 39 on Figure 5 and Table1.

Hialeah Water Treatment Plant

The Hialeah WTP was originally designed in 1924 with a total capacity of 10 mgd. This capacity was doubled later that year and then again in 1935 to reach a total capacity of 40 mgd. In 1946, capacity was increased to 60 mgd, which is the plant's current capacity. In 1991, air strippers with a capacity of 84 mgd were added to the Hialeah treatment process to remove volatile organics from the finished water. The Hialeah WTP receives its source water primarily from the Hialeah-Miami Springs Wellfields, supplemented by the Northwest Well field. This WTP has a current rated capacity of 60 mgd and a basic treatment regimen that includes lime softening with sodium silicate activated by chlorine, recarbonation, chlorination, ammoniation, fluoridation, filtration, and air stripping.

Water quality analysis is performed throughout the year for internal purposes and to meet DERM and DCDH requirements. This water quality analyses includes sampling for: metals, anions, physical and chemical properties, microbiological, organics and volatile organics. These "Typical Average Analyses" are made available to MDWSD consumers annually in a consumer confidence report. Maximum Contaminant Levels (MCLs) set by EPA, FDEP, and Miami-Dade County are also noted in this report.

An item of particular concern at the Hialeah WTP is the presence of small amounts of vinyl chloride, a VOC, in the Hialeah-Miami Springs raw water. The average concentration of vinyl chloride found in the raw water over the past four year is 0.004

mg/l. This is above the MCL of 0.001 mg/l. This volatile constituent is reduced to below detectable limits by the water treatment plant process and by the use of air stripping the finished water.

John E. Preston Water Treatment Plant

The John E. Preston WTP was first designed as a 60 mgd plant and upgraded to 110 mgd in 1980. In 1984, the plant was re-rated to a total capacity of 130 mgd, and in 1988 the plant reached its present capacity of 165 mgd with another addition. In 1991, the plant was modified with an air stripper capacity of 185 mgd to remove VOCs. The John E. Preston WTP obtains its source water from the Northwest Well field and some blended water from the Preston wellfields. The current rated capacity is 165 mgd with a treatment train similar to the Hialeah WTP.

Similar to the Hialeah WTP, the water quality at the John E. Preston WTP is analyzed throughout the year to meet regulatory requirements. This information is made available to MDWSD consumers annually in a consumer confidence report.

The John E. Preston WTP receives raw water from the Northwest Well field that has a relatively high color of over 50 color units (CU) due to high organic content. Total organic carbon (TOC) levels are typically greater than 15 mg/l. Finished water generally has a color range of 10 to 15 CU, which is of particular concern to customers.

The high organics content of the raw water also contributes to the formation of higher levels of disinfection by-products (DBPs), formed when chlorine reacts with the organics.

Remedy Implementation

The Remedial Action took place in two separate phases. The first phase entailed the removal and off-site disposal of hazardous waste soils and debris and the treatment of contaminated groundwater associated with the Miami Drums Site. The activities for this phase were initiated in December 1981 and were completed in January 1982.

The second phase entailed recovering and treating the contaminated groundwater. Although a separate and distinct plume has not been identified to this site, the Biscayne Aquifer Remedial Investigation found that continuous pumping of the Miami Springs and Preston production wells tends to draw associated groundwater contaminants from the former Miami Drums Services Site. Therefore, it was determined that withdrawal and treatment of groundwater at a centralized location (i.e., Preston and Hialeah WTP's) was more favorable than treatment of groundwater at the different sources. 44 and 20 air strippers were added to the Preston and Hialeah WTP's, respectively in 1992 to treat the volatile organic constituents associated with the Miami Drums site and other NPL sites.

System Operation/Operation and Maintenance

The Miami-Dade Water and Sewer Department have been monitoring VOC contamination in the Hialeah Well field, the Upper and Lower Miami Springs Well field and the John E. Preston Well field quarterly from 1988 to 1992 and annually from 1993 to present. The reason for the reduction in the frequency of monitoring was a result of the relaxing of regulations for monitoring at the supply wells. In addition, the MDWSD monitors the raw water influent, the air stripper tower influent and the finish water effluent a minimum of four times per month.

Due to regional contamination at the Hialeah Well field, the Miami Springs Well field and the John E. Preston Well field, these three wells fields were not operative until after the air strippers were installed and functioning at the Hialeah and John Preston Water Treatment Plants in 1992. Prior to 1992, supply water for these two plants was provided from the uncontaminated Northwest Well field. Water is presently blended from both the contaminated and uncontaminated well fields.

Attachment E provides operating data for the different supply wells that provide water to both the Preston and Hialeah Water Treatment Plants. This attachment notes operating data for the month of January 2001. This data shows that on a typical operating day, only around 50% or less of the wells are operating. Mr. Art Baldwin of the MDWSD noted that the operation of the wells are on a rotating schedule and this schedule is based on the maintenance of the wells, pumps, and supply lines and is also based upon the laboratory sampling schedule for testing. Attachment E also shows that the wells pump greater than the rated capacity of the pump. For example, on January 1, 2001, the average supply well provided water at 17.25% more than the rated capacity of each well pumping. Mr. Baldwin stated to reason for this was due to a low headloss in the receiving pipes (a large diameter receiving pipe).

The Medley wellfield is located directly west of the Miami Drum Services Site and was utilized in the past to provide water to both the Preston and Hialeah WTP's on an emergency basis. The Medley wellfield is no longer in operation due to high levels of contamination in groundwater near the wellfield. This well field has not operated since the 1980's. Mr. Baldwin did not know if this well field would ever resume operation. There could be a possibility of this well field starting up again if the demand for water exceeds present supply capacity.

Attachment D provides plant influent, air stripper tower influent and effluent water quality for VOC's and TTHM's during the 2001 operating year. This data shows that the influent VOC concentration to the plant is typically between 1 and 2 ppb for the Hialeah WTP and less than 1 ppb for the Preston WTP. There is some reduction in VOC concentration between the plant influent and the air stripper tower influent. As noted in Appendix A, the air strippers remove VOCs to below detection limits (BDL) during most operations. There have been some detection of VOC's during the sampling of the finished water, however, these have been the exception. The Miami-Dade Sewer Department does provide information to the public on the quality of water being

consumed and this is provided on an annual basis to all customers.

V. Progress Since Last Five-Year Review

This was the first five-year review for the site.

VI. Five Year Review Process

Administrative Components

The Miami Drum Services Five-Year Review team was led by Bill Neimes of the USACE and included Arthur Baldwin of the Miami Dade Water and Sewer Department. A site visit of the Preston Water Treatment Plant was conducted on July 25, 2002. In addition to inspecting the Preston Water Treatment Plant, the Former Miami Drum Services site was also viewed. Several photographs were taken during the site inspection and these photographs are shown in Attachment A.

Community Involvement

Although no activities were planned to involve the community in the five-year review process, the community is made indirectly aware of groundwater contaminants and directly aware of drinking water contaminations through the Miami-Dade Water and Sewer Department public documents.

Document Review

This Five-Year Review consisted of a review of relevant documents including the Miami Drum Services and Biscayne Aquifer ROD. The EPA did not have any documents on Administrative Record and the records were either obtained from the FDEP files in Tallahassee or the Miami Dade Water and Sewer Department files.

Data Review

Groundwater Monitoring

As noted on Figure 6, there are 23 Hialeah or Miami Springs wells and 7 Preston that provide source water to the Preston and Hialeah WTP's. Of the 7 Preston wells, Wells 1 through 6 are situated on the perimeter of the Preston WTP while Well 7 is located near Well 1. Of the 23 Hialeah wells, there are three wells adjacent to the Hialeah WTP, eight wells in the southern Miami Springs well field and 12 wells in the northern Miami Springs well field.

Both the Hialeah Wells and Preston wells have been monitored by the Miami Dade Water and Sewer Department since 1988. From 1988 through 1992 these wells were

monitored quarterly. However, in 1992, public utility monitoring requirements were relaxed to where it was not a requirement to monitor at the wellhead for drinking water systems. Even though there was no mandate for wellhead monitoring, the Miami Dade Water and Sewer Department continued to monitor each of these 30 wells on an annual frequency. Monitoring of these 30 wells is typically performed in the fall season (either in October or November) but there have been certain years where these wells have been monitored during other months of the year. Attachment B denotes the total VOC concentration in both the Hialeah (Miami Springs) wells and Preston wells from 1988 through 2002.

Preston Wells (Seven Wells)

The VOC concentration for the seven Preston wells circumferencing the Preston WTP varied between non-detect and 20 ppb during the years 1988 through 1993 with a general downward concentration trend over this duration. In 1994, the VOC concentration in several of the wells noted steep increases. Specifically, Preston wells 1, 4, and 5 noted approximately a 4X increase in VOC concentration between the September 1993 and November 1994 sampling dates. The increase in VOC concentrations in several of the Preston wells during the 1993-1994 time span may be due to a delayed response from the startup of these wells in 1992. Prior to 1992, the supply wells were not actively pumping groundwater so the contamination may have been localized in the vicinity of each supply well. However, the wells were reactivated in 1992 and the increases in VOC concentrations may be an indication of the regional groundwater quality. By October 1996, VOC concentrations in all seven Preston wells were less than 5 ppb with the exception of Preston Well No. 5. The latest recorded sampling event in April 2002 notes that all seven Preston wells have recorded VOCs of less than 5 ppb.

Miami Springs Lower (Eight Wells)

The Miami Springs Lower Well field are noted on Attachment B as Hialeah Wells 1-8. Similar to the Preston wells, many of the Lower Miami Springs wells noted a general downward VOC concentration trend since the inception of monitoring in 1988 to the latest monitoring date in 2002. The exception to this general downward VOC concentration trend was Well No. 8. Between July 1992 and November 1995, the VOC concentration in this well went from near BDL to over 50 ppb. The most recent monitoring of this well showed VOC concentrations of less than 10 ppb. It is not obvious why only one of the eight Lower Miami Springs wells would note a sharp increase in VOC concentration between 1993 and 1995. Although the increase in VOC concentrations correspond to the general startup date for the recovery wells after air stripper installation at the Water Treatment Plants, the VOC plume was not localized near any specific municipal supply well to note significant differences in VOC concentrations between Well No. 8 and the other seven supply wells. Well No. 8 is located within a residential neighborhood so localized contamination in this well should not be from any industry, dry cleaner store or other potential candidate. Even though

there was a significant increase in VOC concentration in Well No. 8 in the 1992-1995 timeframe, the VOC concentration has subsequently diminished to levels of less than 10 ppb during the most recent sampling event.

Miami Springs Upper (Twelve Wells)

The Miami Springs Upper Well field wells are noted on Attachment B as Hialeah Wells 9, 10, and 14-23. The charts in Attachment B note a general downward VOC concentration over the monitoring period from 1988 through 2002. There have been some periodic spikes over this time period, most notably the VOC concentration spike at Wells No. 17 and No. 23 in 1992, and Well No. 20 in 1994. These VOC concentration spikes may be attributed to the startup of the Miami Springs Upper wellfield after construction of the air strippers at each Water Treatment Plant. The water supply well located nearest the former Miami Drums Services Site is Well No. 9 and the VOC concentration data for this supply well varied between non-detect and 15 ppb over the monitoring period with the most recent VOC concentration indicating 2 ppb.

Hialeah Well field (Three Wells)

The Hialeah Well field are noted in Attachment B as Hialeah Well No. 11-13. The VOC concentration trend for these three wells note two peaks, one in 1990 and the other in the 1994 –1995 timeframe. The peak in the 1994-1995 time frame is similar to supply wells in other wellfields and may be attributed to the initiation of the supply wells in 1992. However, these are the only wells to show a significant increase in VOC concentration in 1990. Natural attenuation may account for the reduction of VOC concentration in these wells after 1990.

Overall Analyses

There have been noticeable reductions in each municipal supply well since the initiation of remedial actions. With the exception of one supply well (Hialeah Well No. 8), all supply wells now are indicating VOC's at less than 5 ppb. This is noticeably different than the 1993-1994 timeframe when many supply wells were noting VOC's levels greater than 20 ppb. It is difficult to determine if these VOC's are being removed at the two water treatment plants or whether other natural phenomena is assisting in VOC reduction. There are several documented sites in which biodegradation of VOC's has significantly contributed to VOC reduction and biodegradation can often be the dominant factor in the removal of VOC contamination. To evaluate whether or not biodegradation is occurring, the U.S. Air Force has developed a screening/scoring mechanism based upon analyses of different parameters. Table 2 provides the list of parameters and the points awarded for each parameter. The full procedure for evaluating biodegradation is provided in Attachment G. It is recommended that the MDWSD consider utilizing this technical approach for evaluating the possible benefits of biodegradation.

Air Monitoring

The Miami-Dade Water and Sewer Department does provide an evaluation of air emissions from the air stripping towers at the Hialeah and Preston Water Treatment Plants. The Hialeah and Preston WTP's are permitted by the State of Florida under Air Operating Permit Number 0250281-004-AV. This air permit is a Title V permit and the most recent permit was issued on June 29, 2000 and expires on June 28, 2005. This air permit provides the monitoring of the VOC's as well as a lime recalcinating kiln, standby diesel generators and two lime silos. Air emissions are not directly monitored at each air stripper stack, but are indirectly monitored by multiplying the influent VOC concentrations by the monthly flow weighted average. As stated in the air permit "The emission of each pollutant ... shall be calculated monthly by mass balance, calculated from the average concentration of the water entering the emission unit and the monthly water flow rate, assuming that all of the pollutants are volatilized to the air. The average influent concentration shall be based on a minimum of four water samples per month, representative of the influent to the permitted emission unit. The monthly flow rate shall be the total volume of water measured that flow through the emission unit each month."

Mr. Richard O'Rourke of the Miami Water and Sewer Department tabulates the air emission data on a monthly basis and this information is provided to the Florida Department of Environmental Protection Southeast District's Air Permitting Section annually. The volatile organic pollutants of concern include the volatiles in the groundwater and volatile organics resulting from the chlorination process. The volatile organics resulting from the chlorination process are noted as trihalomethanes (THM's).

Mr. O'Rourke stated that the air emission limitation has never been exceeded although he did note that there were violations of the previous air permit. The reason for these violations was not due to the mass of volatiles being emitted but was based upon an exceedance of the influent concentration of the volatiles. If the influent concentration exceeded a specific limit, there would be a violation of the air permit. As stated in the previous paragraph, the air permit is now based upon a mass calculation rather than on the concentration of volatiles in the influent. Included in Attachment C is a record of monthly air emission calculations for January 2000 through May 2002. This information documents that the VOC emissions calculated for the Hialeah and Preston WTP's were significantly below permitted emissions. The air permit allows up to 1 ton per 12 month period for each permitted VOC. Of the VOC's being recorded, the most significant VOC contributor to air emissions has been vinyl chloride. The maximum 12 month total emissions for vinyl chloride occurred in January 2000 where the 12-month total VOC emissions was 0.146 tons. This is approximately 7 times less than the permit limitation of 1 ton.

In addition to calculating the mass of volatiles being emitted from the air strippers, the Miami Dade Water and Sewer Department also monitors the ambient air around the two plants for volatile organics. This is not a permit requirement but is performed to document the ambient air quality of the air space in the vicinity of the two water treatment plants.

Influent and Effluent Monitoring

The MDWSD collects samples at both the Hialeah and Preston WTP's a minimum of four times per month. This monitoring frequency is specified in the Title V air permit. Included as Attachment D are the results of monitoring the Hialeah and Preston WTP's during operating year 2001. During most months in 2001, water samples were collected more than four times per month, although water samples were collected only three times in December 2001. Water samples are collected at the treatment plant influent, the air stripper tower influent and the finished water. For both the Hialeah and Preston WTP's, the treatment plant influent VOC concentration was typically higher than the tower influent VOC concentration. This indicates that there is volatilization of contaminants in the treatment plant prior to air stripping. An example of this difference is noted in the October sampling information. For the Hialeah WTP, the average influent VOC concentration to the treatment plant during the month of October was 1.02 ppb and the average VOC concentration to the air strippers during the month of October was 0.54 ppb. The October 2001 sampling indicates a significant percentage of VOC are removed during conventional water treatment process prior to air stripping. The air permit does not consider volatilization of VOC's prior to the air strippers. Adding the emission of volatiles from the conventional treatment plant to the emission of volatiles from the air strippers has not violated the permitted air emission limitations. Although the addition of VOC's being removed by the conventional water treatment process does significantly contribute to the overall plant air emissions, it is apparent that the VOC's entering the water treatment plants have reduced in concentration since the initiation of the air strippers in 1992, and the cumulative air emissions from the conventional water treatment plant and the air strippers are within the permit limitations.

In most sampling events, the effluent VOC concentration was below detection limit. There were a few sampling events where trace amounts of VOC were detected in the effluent. Of the 170 effluent samples taken at both the Hialeah and Preston WTPs, there were four detections of VOC contaminants. These quantifiable detections were still below the MCL's.

Site Inspection

The Five-Year Review site inspection for the Miami Drums Services Site was held on July 25, 2002. Mr. William Neimes from the USACE and Mr. Arthur Baldwin from the Miami-Dade Water and Sewer Department attended the site inspection. Mr. Baldwin provided access to the John E. Preston Water Treatment Plant. At this plant, the

inspection team toured the plant's treatment system, especially the air stripper towers that were integral to the Biscayne Aquifer Sites. There are forty-four air strippers at the Preston Water Treatment Plant and these towers are 14 feet in diameter and 20.5 feet of packing. Mr. Baldwin mentioned that these air stripping towers are cleaned on occasion by replacing the packing with new packing. Based on effluent concentrations of VOC's the air stripping towers are removing any VOC's in the supply water prior to discharging this water to the pump station and transmission lines. There were several photographs taken of the John E. Preston Water Treatment Plant and these are provided in Attachment A.

The Hialeah Water Treatment Plant is located across the street from the John E. Preston Water Treatment Plant and includes twenty air stripping towers. The dimensions of the air stripping towers are similar to the air stripping towers at the John E. Preston Water Treatment Plant. Since the Hialeah Water Treatment Plant utilize similar equipment and processes water similar to the John E. Preston Water Treatment Plant, it was decided against inspecting the Hialeah Water Treatment Plant.

Mr. Baldwin drove to the location of Upper Miami Springs Well No. 9. This supply well is the nearest well to the former Miami Drums Services Site. This well, as well as many of the other supply wells, are located in residential neighborhoods. Two photographs show the location of this well and pump station. In the background on one of these two photographs is the FEC Canal and behind this canal is the former Miami Drums Services Site.

Mr. Baldwin then drove to the William Lehman Operations and Maintenance Center where the former Miami Springs Services Site was located. A photograph provides a panoramic view of this site from Milam Dairy Road.

Interviews

Miami-Dade Water and Sewer Department

Bonnie Wells – (786) 552-8107

Ms. Wells is responsible for Contracts and explained the funding issues. Ms. Wells stated that Miami-Dade County received 41% funding for the construction and operation of the air stripper towers at both the John E. Preston WTP and the Hialeah WTP. The funding for operating the air stripper towers at both these plants expires in September 2002. She stated that the Miami-Dade Water and Sewer Department will continue to operate these air stripper towers after the funding from the EPA has dissipated.

Arthur Baldwin – (305) 299-8289

Mr. Baldwin provided a site tour of the John E. Preston WTP, some of the municipal supply wells and at the former Miami Drums Services site. While at the Preston WTP,

we reviewed plant operational records. Mr. Baldwin also answered questions concerning to operation of the different supply wells, providing water to the two water treatment plants.

Richard O'Rourke – (786) 552-8123

Richard O'Rourke provided air compliance records for the air strippers at the Preston and Hialeah WTP. Mr. O'Rourke explained that the air permitting requirements are based on a Title V Air Operating permit from the State of Florida. Mr. O'Rourke noted that the permit could be viewed and downloaded via a FDEP web site.

Ray Diaz – (305) 275-3614

Mr. Diaz provided VOC concentration data for the Preston and Miami Springs wellfields for the monitoring period from 1988 until 2002. Mr. Diaz explained the sampling methodology (annual sampling in the fall quarter) for these 30 supply wells.

Noel Grant – (305) 275-3176

Mr. Grant provided influent and effluent data for the Hialeah and Preston Water Treatment Plants during 2001.

DERM

Becky Varley – (305) 372-6824

Ms. Varley works for Dade Environmental Resource Management and was called to research the two petroleum sites that were noted as contaminated under the Petroleum Cleanup Program. Ms. Varley stated that one of the sites is an active facility and is in the process of being remediated. The site is identified as Florida East Coast Railway Hialeah Locomotive Service Area. The Facility ID Number is 138622168. As noted on Figure 8, this facility is located approximately 1/3 mile from Miami Springs Well No. 9. Figure 9 shows the estimated free product plume at this site. Remedial efforts have been undertaken to alleviate this free product plume.

John Hickey – (305) 372-6713

Mr. Hickey was called to research records associated with the remediation of the Miami Drums Services site. Mr. Hickey's assistant responded by noting that DERM does not have detailed and thorough records prior to 1983. Mr. Hickey also noted that he has visited the local library (local repository) to research site records and he did not find much information available at the local library.

Florida Department of Health

Lee Skornia – (850) 245-4444 X 2292

Mr. Skornia works for the Florida Department of Health in Tallahassee, Florida and his

name was provided as a contact person for identifying any private potable wells in the vicinity of the Miami Drums Services Site. Mr. Skornia noted that there were no registered private wells within a mile of the former site. Mr. Skornia stated that there was a FPL irrigation well near the former site and there were recovery wells from a petroleum contaminated site near the former site. Mr. Skornia faxed a map identifying the location of the irrigation well along with identifying the two petroleum sites. This fax is provided as Figure 7.

VII. Technical Assessment

Question A. Is the remedy functioning as intended by the decision documents?

There have been two decision documents associated with the Miami Drums Services Site. The first decision document, the Miami Drums ROD, provided information of the remedial activities conducted at this site. The removal of drums, and the excavation and removal of contaminated soils from the site achieved the remedial objectives to minimize the migration of contaminants to the groundwater and to prevent contact with contaminants in the soil. There was an alternative to excavate additional soils to eliminate low levels of mercury contamination in the soils, but this was decided against, given the naturally basic water (pH 7-8.5) in the groundwater. This site has been converted to a maintenance facility for the Dade County Rapid Rail Transit Project.

The second decision document, the Biscayne Aquifer Sites ROD, included an alternative for the widespread groundwater contamination near the Miami Drums Services Site. The Miami Drums Services Site is partially attributable to this widespread groundwater contamination plume. This decision document provides for treatment of contaminated groundwater at two Regional Water Treatment Plants. Contaminated groundwater will be supplied to these plants through existing supply wells. Groundwater monitoring records from 1988 to present indicate a steady VOC concentration reduction for many of the municipal supply wells.

Question B. Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of the remedy selection still valid?

Soils at the Miami Drums Services Site were excavated based on three criteria: (1) visibly contaminated soils; (2) all debris and structures; (3) soils displaying parameter values significantly higher than 10 times the State's minimum criteria for groundwater based on EP toxicity analyses. A description of the soil excavation is noted on Figure 10. Since this time, the State has promulgated soil cleanup levels based either on leachability standards or toxicity standards. These standards are identified in Chapter 62-777, Florida Administrative Code. During the review of files at the State of Florida Records Center in Tallahassee, Florida, efforts were made to obtain documents noting the cleanup levels achieved by the remedial activities during the 1981-1982 timeframe.

A report Evaluation of the Cleanup Activities Already Undertaken at the Miami Drum Services Hazardous Waste Site noted the cleanup efforts accomplished by the remediation contractor. This report notes that mercury contaminated soils were identified but were not removed. These soils were determined to be contaminated based upon the criteria of "10 times the State's minimum criteria for groundwater based upon the EP toxicity procedure". These soils in excess of this factor of 10 criteria are noted on Figure 11. Provided the upper two feet of clean fill material or an impermeable surface cap such as asphalt or concrete is maintained across the site, the soil removal action previously conducted is considered sufficient by DERM to comply with the cleanup requirements applicable to this site. However, upon site closure, a No Further Action with Conditions will apply which will require a restrictive covenant to ensure that the surface seal (fill, concrete, or asphalt) is maintained.

Several priority pollutants have been identified in the Biscayne Aquifer Sites ROD. These include inorganics, volatile organics, and other organic compounds. The list of contaminants included in the Biscayne Aquifer Sites ROD is listed in the table below. Columns were created to identify the cleanup goals in the ROD and comparing these cleanup goals to: (1) the Federal MCL's; (2) the State of Florida MCL's; and (3) the State of Florida Cleanup Target Levels, as noted in Chapter 62-777, F.A.C. Even though the list of contaminants is extensive, the only priority pollutants that were most prevalent throughout the area and in the finished water from the Hialeah and Preston WTP's were the Volatile Organic Compounds. Although inorganics, other priority pollutant organics, pesticides and PCB's were detected in some wells throughout the study area, the concentration of these constituents in the supply wells and the two water treatment plants (Hialeah and Preston) are below MCL's. Upon site closure under CERCLA, DERM would require that representative groundwater samples be obtained from the site to determine the current conditions at that time. If groundwater impacts are present above sub-regional groundwater contaminant concentrations, DERM may require additional assessment at the site and, unless remediated to sub-regional contaminant concentrations, a No Further Action with Conditions requiring a restrictive covenant prohibiting on-site water usage.

TABLE 4 - TABLE of ARAR's

(Note: all concentrations in ug/l)

Contaminant	Cleanup Goals in ROD	Current Federal MCL (40CFR 141)	State MCL (FAC 62-550)	State Cleanup Target Levels (FAC 62-777)
Inorganics				
Arsenic	50	50	50	
Cadmium	10	5	5	
Chromium	50	100	100	
Lead	50	15	15	
Mercury	2	2	2	
Selenium	10	50	50	

Volatile Organics				
Vinyl Chloride	1	2	1	
1,1,2,2-Tetrachloroethane	0.2			0.2
Benzene	0.7	5	1	
Methylene Chloride	0.2	3	3	
1,1-Dichloroethane	0.9			70
1,1-Dichloroethene	0.04	7	7	
Acrylonitrile	0.34			1
Chlorobenzene	488	100	100	
1,2-Dichloroethene (cis & trans)	270	cis – 70 trans – 100	cis – 70 trans – 100	
Toluene	340	1000	1000	
m, o & p – xylene	620 (total)	10,000 (total)	10,000 (total)	
Trichloroethene	28	5	3	
Ethyl benzene	1,400	700	700	
Tetrachloroethene	9	5	3	
Chloroform	100			5.7
Bromodichloromethane	100			---
1,1,1 – Trichloroethane	22	200	200	
Chloromethane				2.7
Chloroethane				12
Other Priority Pollutant Organics				
Chrysene	0.2			4.8
Anthracene	0.2			2100
Benzo (a) anthracene	0.2			0.2
Benzo (b & k) fluoranthene	0.2			b – 0.2 k – 0.5
Benzo (a) pyrene	0.2	0.2	0.2	
Benzo (ghi) perylene	0.2			210
Phenanthrene	0.2			210
Pyrene	0.2			210
Fluoranthene	0.2			280
Indeno (1,2,3-cd) pyrene	0.2			0.2
2,4 – Dimethylphenol	400			140
2,4 – Dinitrophenol	70			14
4 – Nitrophenol	70			56
Pentachlorophenol	30	1	1	
Phenol	3500			10
Bis (2-ethylhexyl) Phthalate	6000	6	6	
Benzyl Butyl Phthalate				---
Pesticides and PCBs				
PCB-1254	0.00008			
PCB-1260				
PCB (total)	0.00008	0.5	0.5	

4,4'-DDT	0.00002			0.1
2,4-D	100	70	70	
Silvex (2,4,5-TP)	10	50	50	
Endosulfan Sulfate	--			---

Subsequent to the issuance of the Biscayne Aquifer ROD, Dade County developed a code that prohibits the private use of groundwater wells for drinking water in areas where water main is available. Section 24-12(2)(Q) of the Dade County Code. In addition, Dade County has implemented a program for the protection of the Biscayne Aquifer (the Biscayne Aquifer Protection Plan) .

Question C. Has any other information come to light that could call into question the protectiveness of the remedy?

There is no other information that questions or challenges the protectiveness of the remedy.

Technical Assessment Summary

According to the data reviewed, the site inspection, and the interviews, the remedy is functioning as intended by the two RODs. The Former Miami Drums Services Site has subsequently been developed by Miami-Dade County and is now incorporated by the William Lehman Operations and Maintenance Center. The Biscayne Aquifer Sites ROD included a regional approach to remediating the contaminated aquifer. Through the periodic use of the water supply wells in the contaminated area, there has been a noticeable VOC reduction in many of these water supply wells.

VIII. Issues

Issue	Currently Affects Protectiveness (Y/N)	Affects Future Protectiveness (Y/N)
Continue annual monitoring of water supply wells and provide a summary report on the reduction of VOC's in supply wells associated with treatment remedy	N	N
Determine if reduction in VOC's is primarily through pump and treat or if biodegradation of VOC's is occurring at site	N	N
Determine volatilization of VOC's through conventional water treatment plant in addition to calculations being performed for the air strippers	N	N
Update local repository with applicable reports	N	N
Issue a No Further Action with Conditions upon site closure. This requires a restrictive covenant.	N	Y

IX. Recommendations and Follow-up Actions

Issue	Recommendations/ Follow-up Actions	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness? (Y/N)	
					Current	Future
report annual monitoring of VOC data	continue to sample supply wells annually for VOC's and provide this information in a summary report	MDWSD	EPA		N	N
biodegradation evaluation	analyze supply wells for biodegradation parameters	MDWSD	EPA		N	N
volatilization of VOC's at plant	calculate total mass of volatiles emitted at treatment plant	MDWSD	FDEP		N	N
update repository	review repository and update files	MDWSD & DERM	EPA		N	N
Restrictive Covenant	Upon site closure, this should be required to ensure surface seal is maintained	DERM	EPA		N	Y

X. Protectiveness Statement

Based upon records in the FDEP files in Tallahassee, Florida, the selected remedy, as executed, appears to remain protective of human health and the environment. Continued groundwater monitoring at each municipal supply well, and the water treatment plant influent and effluent should be performed and documented to ensure long-term protectiveness.

Long-term protectiveness of the remedial action for the Miami Drum Services Site is maintained by continued operation of the Dade County Transit Maintenance and Repair Facility. Long-term protectiveness of the remedial action for the groundwater contaminant plume is through continued monitoring of municipal supply wells and continued treatment of the groundwater at both the John E. Preston and Hialeah Water Treatment Plants.

XI. Next Review

The next five-year review for the Miami Drums Superfund Site is required by September 2007, five years from the date of this review.

Attachment F

Documents Reviewed

Phase I -- Evaluation of the Clean-up Activities Already Undertaken at the Miami Drum Services Hazardous Waste Site, Dade County, Florida, CH2M Hill, 1982.

Superfund Record of Decision: Biscayne, Aquifer Sites, FI (EPA ROD RO4-85-004)

Phase II -- Sampling, Analytical, and Investigative Program for the Protection of the Biscayne Aquifer and Environment in North Dade County, Florida, CH2M Hill, 1984.

Remedial Investigation for Miami Drum Services Site, Florida, Florida Department of Environmental Regulation, November 1983.

Geophysical and Hydrogeological Investigation of the Miami Drum Site, Technos, Inc. February, 1983.

Record of Decision for the Miami Drum Services Site, Dade County, Florida, September 13, 1982.

Field Investigations of Uncontrolled Hazardous Waste Sites, FIT Project, Ecology and Environment, Inc. December, 1981.

Phase III -- Feasibility of Remedial Actions for the Protection of the Biscayne Aquifer in Dade County, Florida, CH2M Hill, May, 1995.

Draft Water Facility Master Plan, CH2M Hill, March 2000.

TABLES

Table 2. Owners, construction details, and hydraulic data for supply wells in Dade County

[See figure 5 for site locations. USGS, U.S. Geological Survey; diameter, in inches; production interval, in feet below land surface; discharge, in gallons per minute; drawdown, in feet; pumping period, in hours; specific capacity, in gallons per minute per foot; transmissivity, in feet squared per day (270 x specific capacity); OH, open hole; S, screen; —, no data]

Site No.	Owner's well No.	USGS supply well No.	Latitude/longitude	Diameter	Finish	Production interval	Discharge	Drawdown	Pumping period	Specific capacity	Estimated transmissivity
34	1	S-3040	254234802906	16	OH	20 - 40	1,350	1.13	2	1,200	320,000
	2	S-3041	254234802906	16	OH	19 - 50	1,375	.25	2	5,500	1,500,000
35	1	—	254413801642	12	OH	10 - 20	—	—	—	—	—
	2	—	254413801640	6	OH	10 - 20	—	—	—	—	—
	3	—	254412801640	12	OH	10 - 20	—	—	—	—	—
36	1	—	254506801638	8	OH	10 - 20	—	—	—	—	—
	2	—	254507801638	6	OH	10 - 20	—	—	—	—	—
	3	—	254507801637	8	OH	10 - 20	—	—	—	—	—
37	1	—	254507802257	3	—	30 - 110	—	—	—	—	—
	2	—	254514802257	2	—	— - 110	—	—	—	—	—
	3	—	254514802253	4	—	30 - 200	—	—	—	—	—
	4	—	254523802257	2	—	— - 110	—	—	—	—	—
	5	—	254527802254	4	—	30 - 120	—	—	—	—	—
	6	—	254517802230	4	—	30 - 130	—	—	—	—	—
	7	—	254518802229	4	—	30 - 120	—	—	—	—	—
	8	—	254519802232	4	—	— - 200	—	—	—	—	—
	9	—	254527802232	4	—	30 - —	—	—	—	—	—
	10	—	254519802223	4	—	30 - 115	—	—	—	—	—
	11	—	254516802223	2	—	— - 120	—	—	—	—	—
	12	—	254518802224	2	—	— - 120	—	—	—	—	—
	13	—	254509802216	2	—	— - 120	—	—	—	—	—
	14	—	254509802211	2	—	— - 120	—	—	—	—	—
	15	—	254517802212	2	—	— - 120	—	—	—	—	—
	16	—	254519802212	2	—	— - 120	—	—	—	—	—
	17	—	254509802259	2	—	— - 100	—	—	—	—	—
	18	—	254500802230	6	—	25 - —	—	—	—	—	—
	19	—	254527802254	4	—	25 - —	—	—	—	—	—
	20	—	254523802224	2	—	— - —	—	—	—	—	—
	21	—	254530802226	3	—	30 - —	—	—	—	—	—
	22	—	254500802230	6	—	30 - —	—	—	—	—	—
38	1	—	254946802126	8	—	— - 60	—	—	—	—	—
	2	—	254634802126	12	—	— - 60	—	—	—	—	—
	3	—	254633802126	12	—	— - 70	—	—	—	—	—
39	1	S-1476	254946801715	—	OH	66 - 107	2,780	1.6	—	1,740	470,000
	2	S-1477	254952801716	—	OH	66 - 107	2,780	3.4	2	818	220,000
	3	S-1478	254958801716	—	OH	66 - 107	4,170	4.44	—	938	250,000
	4	S-1479	254948801710	—	OH	66 - 107	2,780	1.70	2	1,640	440,000
	5	S-1480	254953801710	—	OH	66 - 107	2,780	2.40	2	1,160	310,000
	6	S-1481	254958801710	—	OH	66 - 107	2,780	3.82	2	490	130,000
	7	S-3000	254943801720	42/35	OH	65.5 - 106.0	5,560	4.67	2	1,160	320,000
40	11	S-11	254938801709	14	OH	85 - 91	—	—	—	—	—
	12	S-12	254942801709	14	OH	83 - 90	—	—	—	—	—
	13	S-13	254938801712	14	OH	83 - 95	—	—	—	—	—
41	9	S-3021	254953801818	14	OH	82.0 - 96.1	3,330	8.5	—	392	110,000
	10	S-3022	254945801731	14	OH	116 - 146	—	—	—	—	—
	14	S-3140	254943801727	14	OH	67.6 - 73.0	2,520	11.0	—	229	62,000
	15	S-15	254945801737	14	OH	75.7 - 85.0	2,310	9.9	—	234	63,000
	16	S-16	254945801745	14	OH	77.0 - 90.5	2,560	5.5	—	465	130,000
	17	S-17	254936801737	14	—	79 - 87	2,450	5.3	—	462	120,000
	18	S-3023	254945801756	14	OH	80.4 - 90.7	2,890	6.4	—	452	120,000
	19	S-324	254945801805	14	OH	80.0 - 97.3	2,400	8.9	—	270	73,000
	20	S-3025	254937801748	14	OH	84.7 - 93.2	2,490	6.0	—	414	110,000
	21	S-3026	254937801757	14	OH	86.2 - 94.5	2,640	7.8	—	339	92,000
	22	S-3027	254937801803	14	OH	82.1 - 93.2	2,470	4.5	—	548	150,000
	23	S-3028	254953801811	14	OH	84.0 - 97.0	2,880	16.3	—	177	48,000

Table 2. Owners, construction details, and hydraulic data for supply wells in Dade County—Continued

[See figure 5 for site locations. USGS, U.S. Geological Survey; diameter, in inches; production interval, in feet below land surface; discharge, in gallons per minute; drawdown, in feet; pumping period, in hours; specific capacity, in gallons per minute per foot; transmissivity, in feet squared per day (270 x specific capacity); OH, open hole; S, screen; —, no data]

Site No.	Owner's well No.	USGS supply well No.	Latitude/longitude	Diameter	Finish	Production interval	Discharge	Drawdown	Pumping period	Specific capacity	Estimated transmissivity
42	1	S-1	254853801714	14	OH	60 - 67	3,800	7.1	—	540	150,000
	2	S-2	254848801720	14	OH	79 - 96	—	—	—	—	—
	3	S-3	254854801723	14	OH	52 - 62	—	—	—	—	—
	4	S-4	254859801716	14	—	84 - 94	2,730	6.7	—	407	110,000
	5	S-5	254857801733	14	OH	82 - 100	—	—	—	—	—
	6	S-3139	254853801742	14	—	49 - 63	—	—	—	—	—
	7	S-7	254847801751	14	OH	49 - 62	—	—	—	—	—
	8	S-8	254848801737	14	OH	50 - 64	1,790	16.2	—	111	30,000
43	1	S-3005	255019801859	42	OH	59 - 132	2,780	1.7	2	1,640	440,000
	2	S-3006	255019801859	42	OH	54 - 131	2,780	3.5	2	794	210,000
	3	S-3007	255019801859	42	OH	65.9 - 132.0	2,780	2.0	2	1,390	380,000
	4	S-3008	255019801859	42	OH	54.5 - 128.5	2,780	4.0	2	695	190,000
	5	S-3009	255019801859	42	OH	54.5 - 128.3	2,780	2.0	2	1,390	380,000
	6	S-3010	255019801859	42	OH	55 - 131	2,780	2.0	2	1,390	380,000
44	1	S-3042	254909802100	8	—	— - 60	—	—	—	—	—
	2	S-3043	254909802100	8	—	— - 60	—	—	—	—	—
	A	—	254848802023	10	—	— - 80	—	—	—	—	—
	B	—	254848802023	10	—	— - 80	—	—	—	—	—
	C	—	254848802023	10	—	— - 90	—	—	—	—	—
	D	—	254848802023	10	—	— - 90	—	—	—	—	—
45	1	—	254936802503	42/24	OH	40 - —	2,780	.38	2	7,410	2,000,000
	2	—	254943802503	42/24	OH	40 - —	2,780	.77	2	3,610	970,000
	3	—	254951802503	42/24	OH	40 - —	—	—	—	—	—
	4	—	254958802504	42/24	OH	40 - —	—	—	—	—	—
	5	—	255005802504	42/24	OH	40 - —	—	—	—	—	—
	6	—	255012802504	42/24	OH	40 - —	—	—	—	—	—
	7	—	255020802504	42/24	OH	40 - —	—	—	—	—	—
	8	—	255028802505	42/24	OH	40 - —	2,780	.42	2	6,670	1,800,000
	9	—	255028802449	42/24	OH	40 - —	2,780	.38	2	7,410	2,000,000
	10	—	255035802450	42/24	OH	40 - —	—	—	—	—	—
	11	—	255043802450	42/24	OH	40 - —	—	—	—	—	—
	12	—	255051802451	42/24	OH	40 - —	2,780	.38	2	7,410	2,000,000
	13	—	255058802451	42/24	OH	40 - —	—	—	—	—	—
	14	—	255106802451	42/24	OH	40 - —	—	—	—	—	—
	15	—	255113802451	42/24	OH	40 - —	2,780	.67	2	4,150	1,100,000
46	1	—	255038800737	24	OH	144 - 171	3,900	4	2	980	260,000
47	1	—	255221801058	8	OH	45 - 47	520	1.0	2	520	140,000
	2	—	255211801059	8	OH	45 - 47	520	1.0	2	520	140,000
	3	—	255209801059	8	OH	68 - 69	685	1.5	2	460	120,000
48	1	S-3129	255304801302	12	OH	78 - 110	—	—	—	—	—
	2	S-3130	255306801302	12	OH	89 - 104	—	—	—	—	—
	3	S-3131	255304801316	12	OH	46 - 60	—	—	—	—	—
	4	S-3132	255306801316	12	OH	57 - 65	—	—	—	—	—
	5	S-3133	255304801330	12	OH	66 - 107	—	—	—	—	—
	6	S-3134	255306801330	12	OH	47 - 56	—	—	—	—	—
	7	S-3135	255317801317	12	OH	52 - 60	—	—	—	—	—
	8	S-3136	255317801315	12	OH	52 - 61	—	—	—	—	—
49	1	—	255258801422	6	—	— - —	—	—	—	—	—
	2	—	255300801421	6	—	— - —	—	—	—	—	—
	3	—	—	8	OH	40 - —	450	—	1.5	—	—
50	1	—	255233802237	16	—	— - 70	—	—	—	—	—
	2	—	255234802233	10	OH	20 - 24	—	—	—	—	—

Table 3. Analytical Parameters and Weighting for Preliminary Screening

Analyte	Concentration in Most Contaminated Zone	Interpretation	Points Awarded
Hydrogen ^a	< 0.5 mg/L	Tolerated; suppresses reductive dechlorination at higher concentrations	3
Oxygen ^a	> 1 mg/L	Vinyl chloride may be oxidized aerobically, but reductive dechlorination will not occur	3
Nitrate ^a	< 1 mg/L	May compete with reductive pathway at higher concentrations	2
Iron (II) ^a	> 1 mg/L	Reductive pathway possible	3
Sulfate ^a	< 20 mg/L	May compete with reductive pathway at higher concentrations	2
Sulfide ^a	> 1 mg/L	Reductive pathway possible	3
Methane ^a	> 0.1 mg/L	Ultimate reductive daughter product	2
	> 1	Vinyl chloride accumulates	3
	< 1	Vinyl chloride oxidizes	
Oxidation reduction potential ^a	< 50 mV against Ag/AgCl	Reductive pathway possible	< 50 mV = 1 < -100 mV = 2
pH ^a	5 < pH < 9	Tolerated range for reductive pathway	
DOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature ^a	> 20°C	At T > 20°C, biochemical process is accelerated	1
Carbon dioxide	> 2x background	Ultimate oxidative daughter product	1
Alkalinity	> 2x background	Results from interaction of carbon dioxide with equifer minerals	1
Chloride ^a	> 2x background	Daughter product of organic chlorine; compare chloride in plume to background conditions	2
Hydrogen	> 1 nM	Reductive pathway possible; vinyl chloride may accumulate	3
Hydrogen	< 1 nM	Vinyl chloride oxidized	
Volatile fatty acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2
BTEX ^a	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2
Perchloroethene ^a		Material released	
Trichloroethene ^a		Material released or daughter product of perchloroethene	2 ^b
Dichloroethene ^a		Material released or daughter product of trichloroethene; If amount of <i>cis</i> -1,2-dichloroethene is greater than 80% of total dichloroethene, it is likely a daughter product of trichloroethene	2 ^b
Vinyl chloride ^a		Material released or daughter product of dichloroethenes	2 ^b
Ethene/Ethane	< 0.1 mg/L	Daughter product of vinyl chloride/ethene	> 0.01 mg/L = 2 > 0.1 = 3
Chloroethane ^a		Daughter product of vinyl chloride under reducing conditions	2
1,1,1-Trichloroethane ^a		Material released	
1,1-dichloroethane ^a		Daughter product of trichloroethene or chemical reaction of 1,1,1-trichloroethane	

^a Required analysis.^b Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

FIGURES

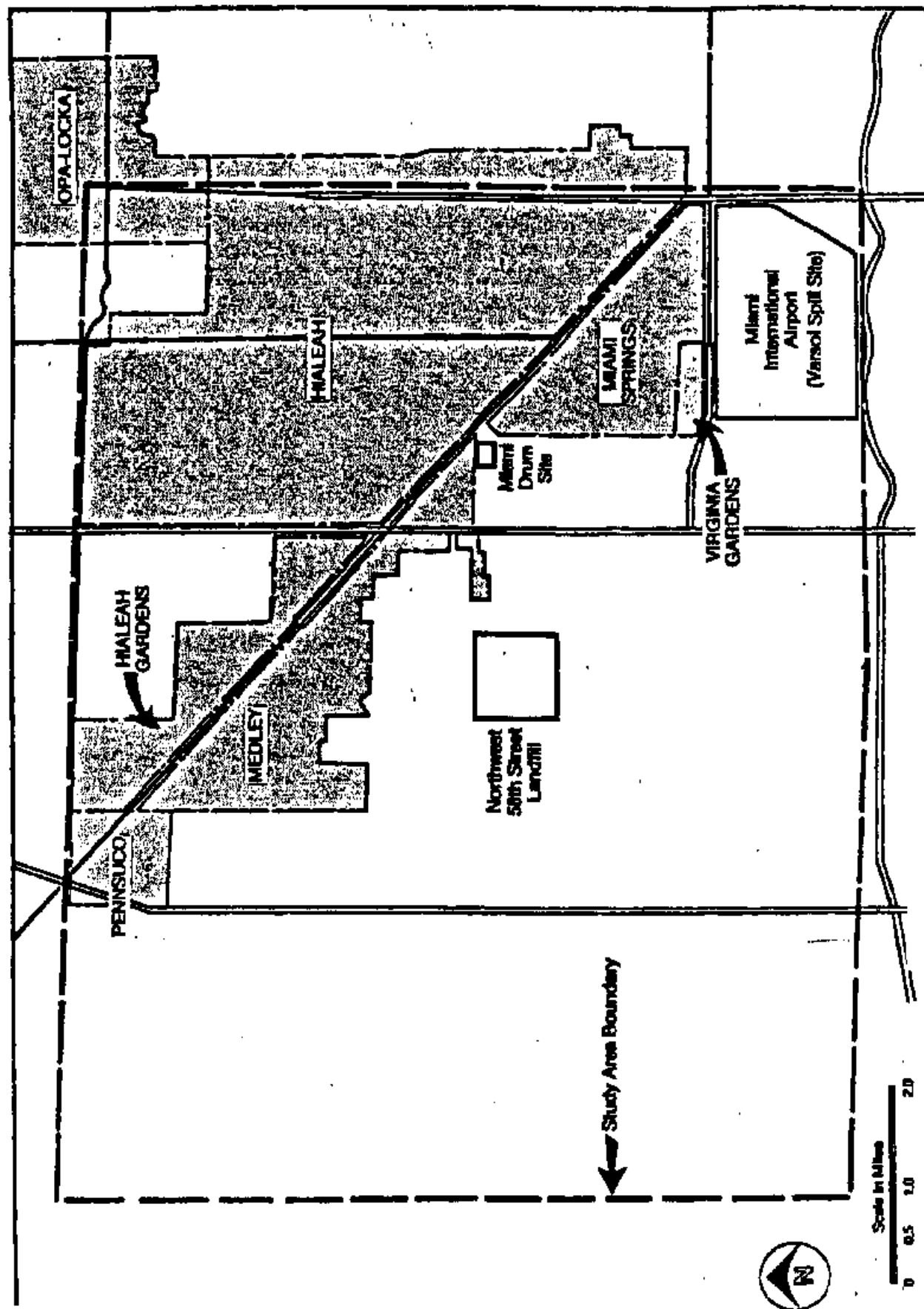


Figure 1 - Biscayne Aquifer Sites Study Area
Ref: EPA ROD R04-85-004; September 1985

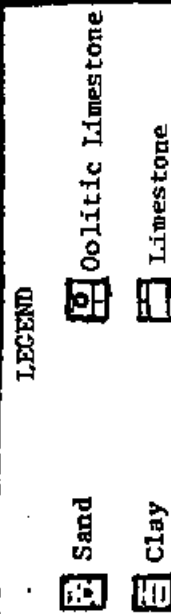
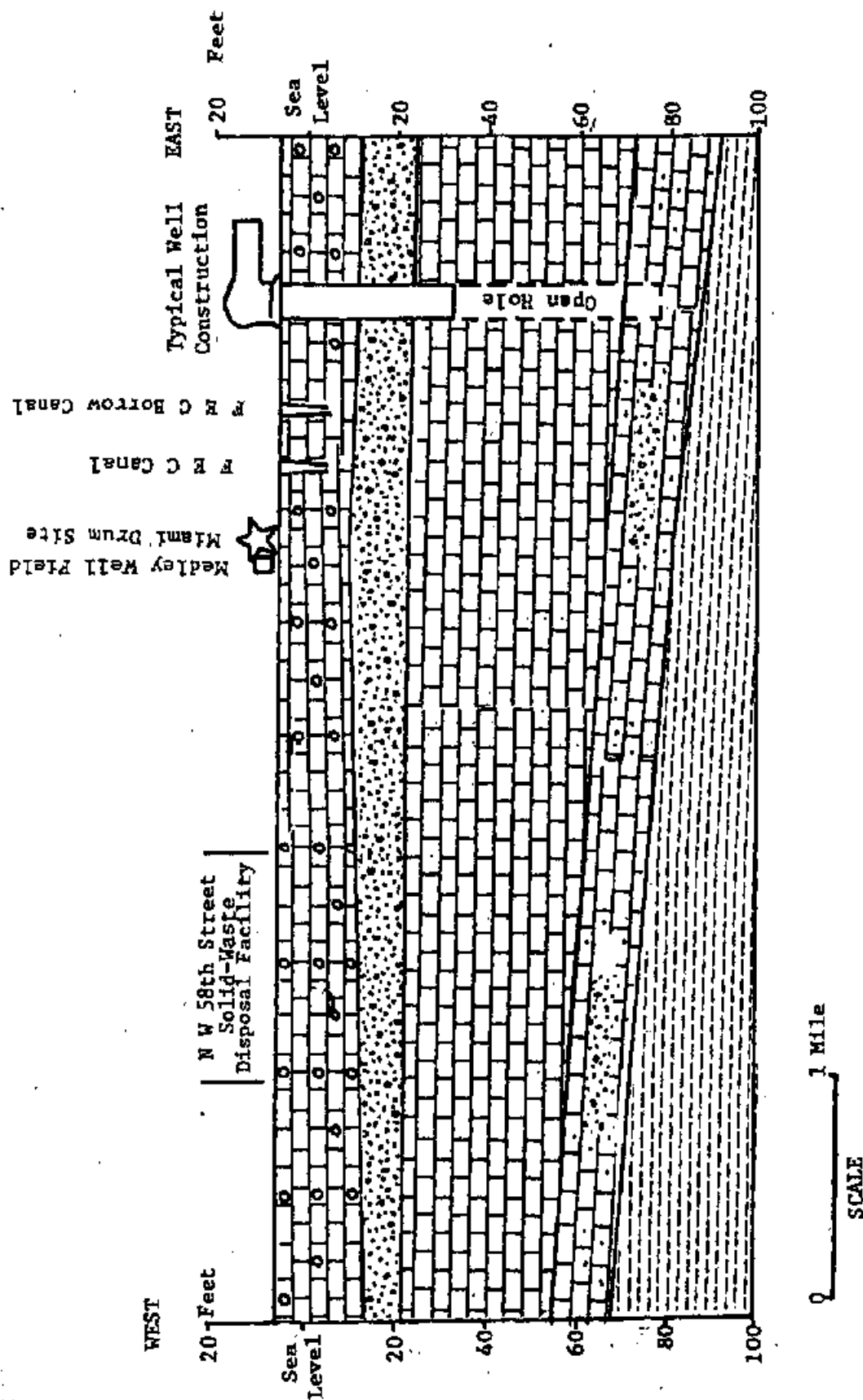
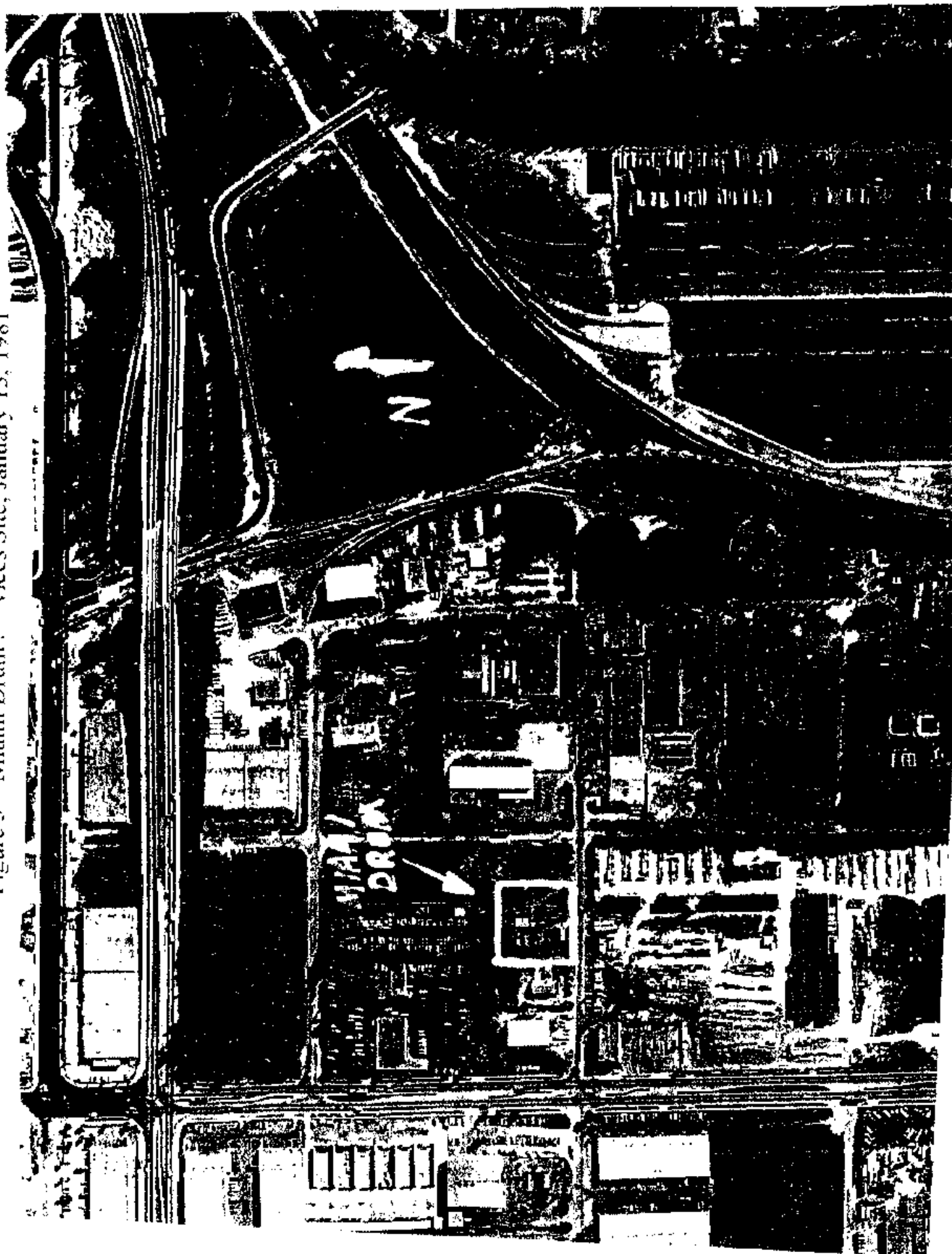
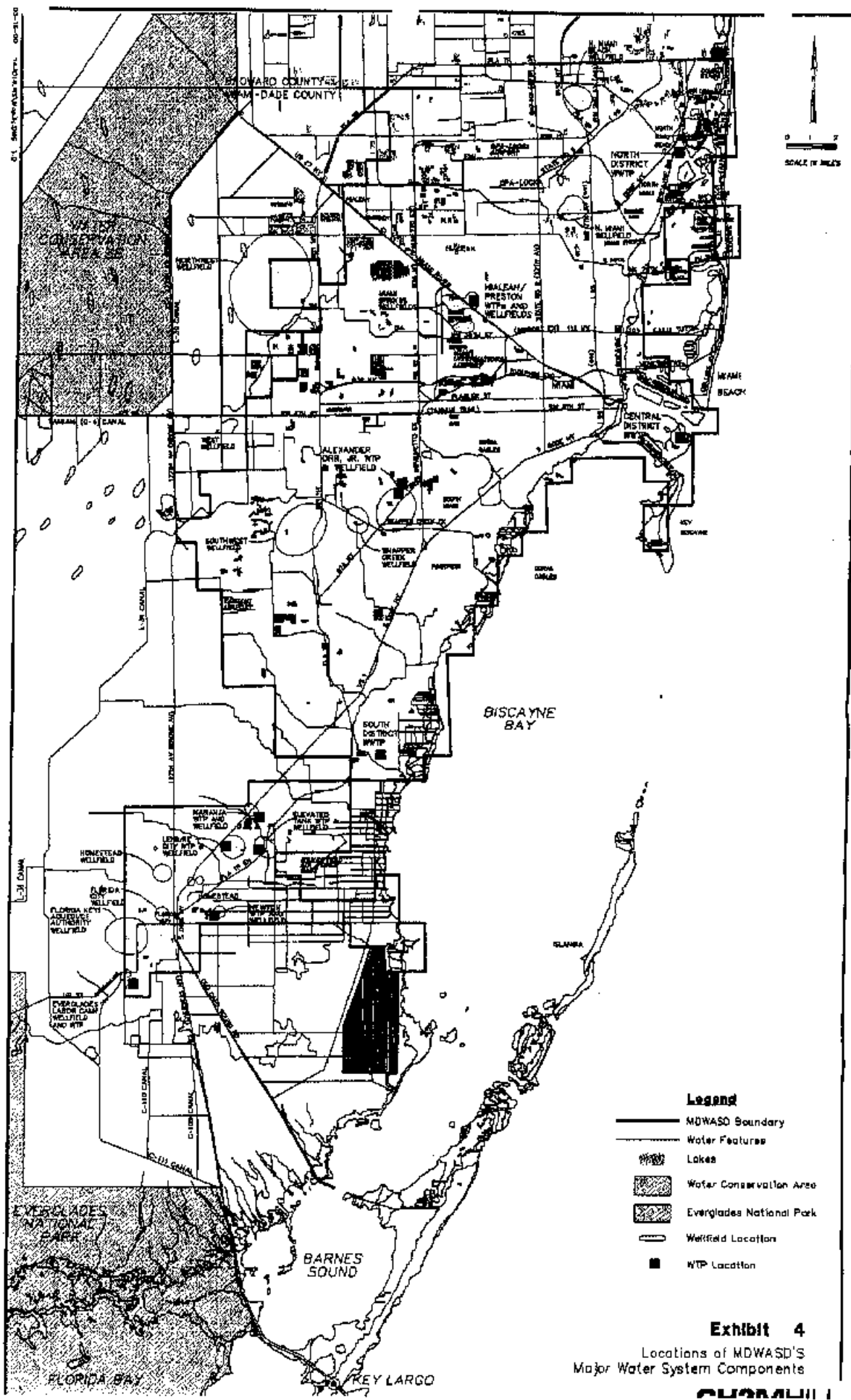


Figure 2 - Generalized Hydrogeologic Cross Section in Vicinity of
Miami Drums Services Site
Ref: Ecology and Environment, Inc.; December 1981

Figure 3 - Miami Drum Services Site; January 13, 1981

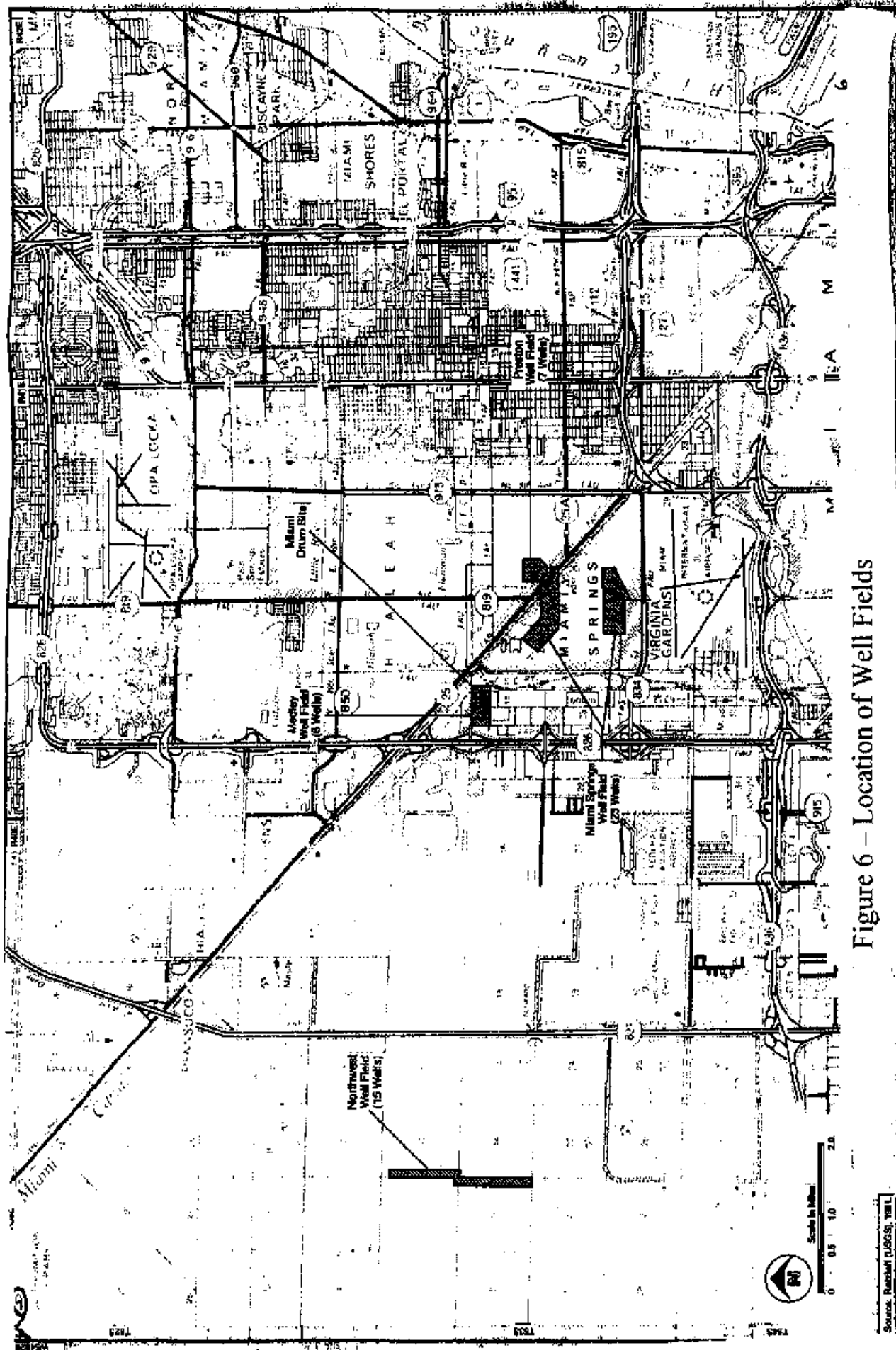




Legend

- MDWASO Boundary
- Water Features
- Lakes
- ▨ Water Conservation Area
- ▨ Everglades National Park
- Wellfield Location
- WTP Location

Exhibit 4
Locations of MDWASO'S
Major Water System Components



[illegible]

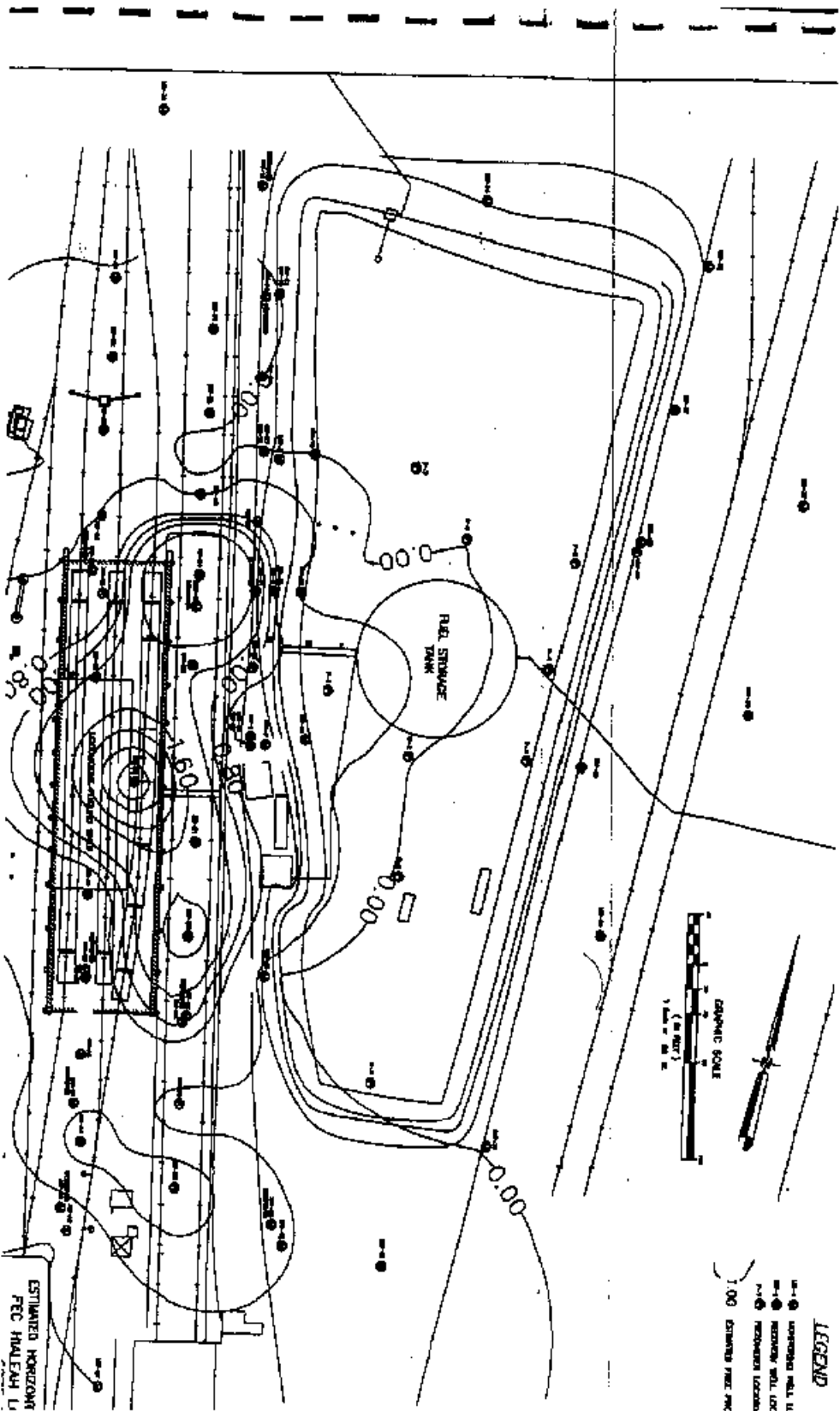
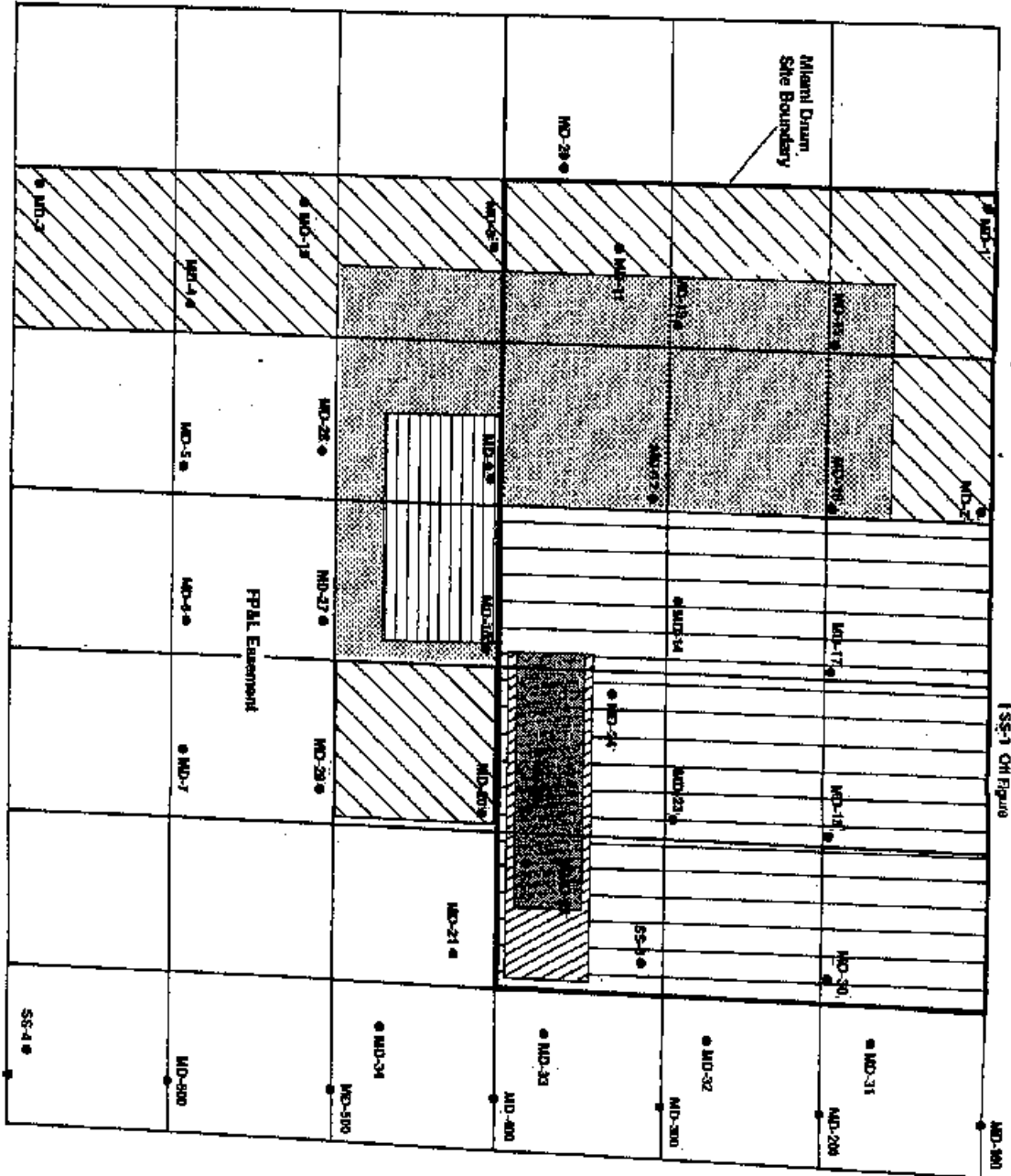


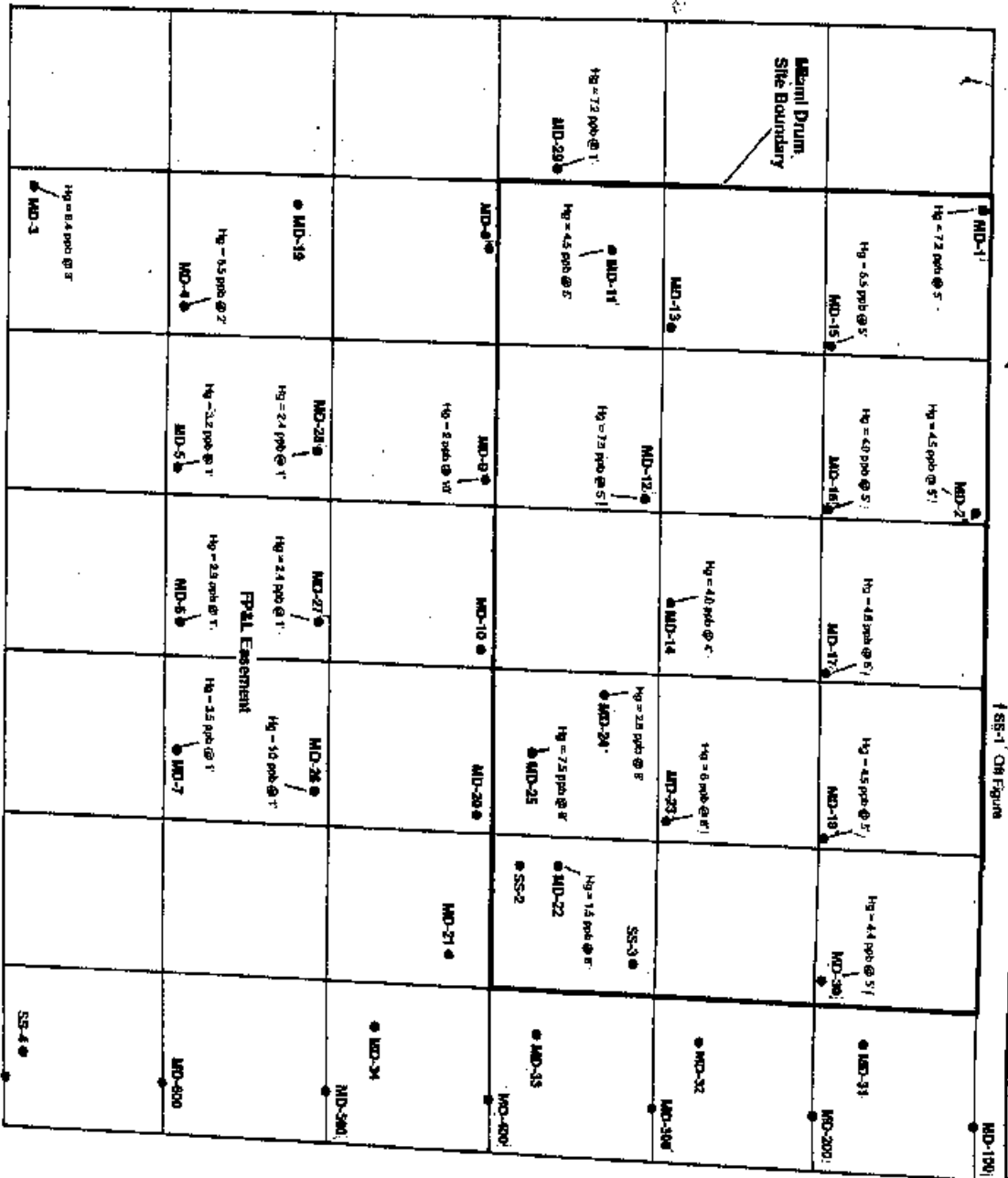
Figure 9 – Estimate Free-Product Plume – Florida East Coast
 Railway – Hialeah Locomotive Service Area

Draw map after Endogard CH Materials Co. Figure

1" = 33.3'



Depth of Soils Excavated



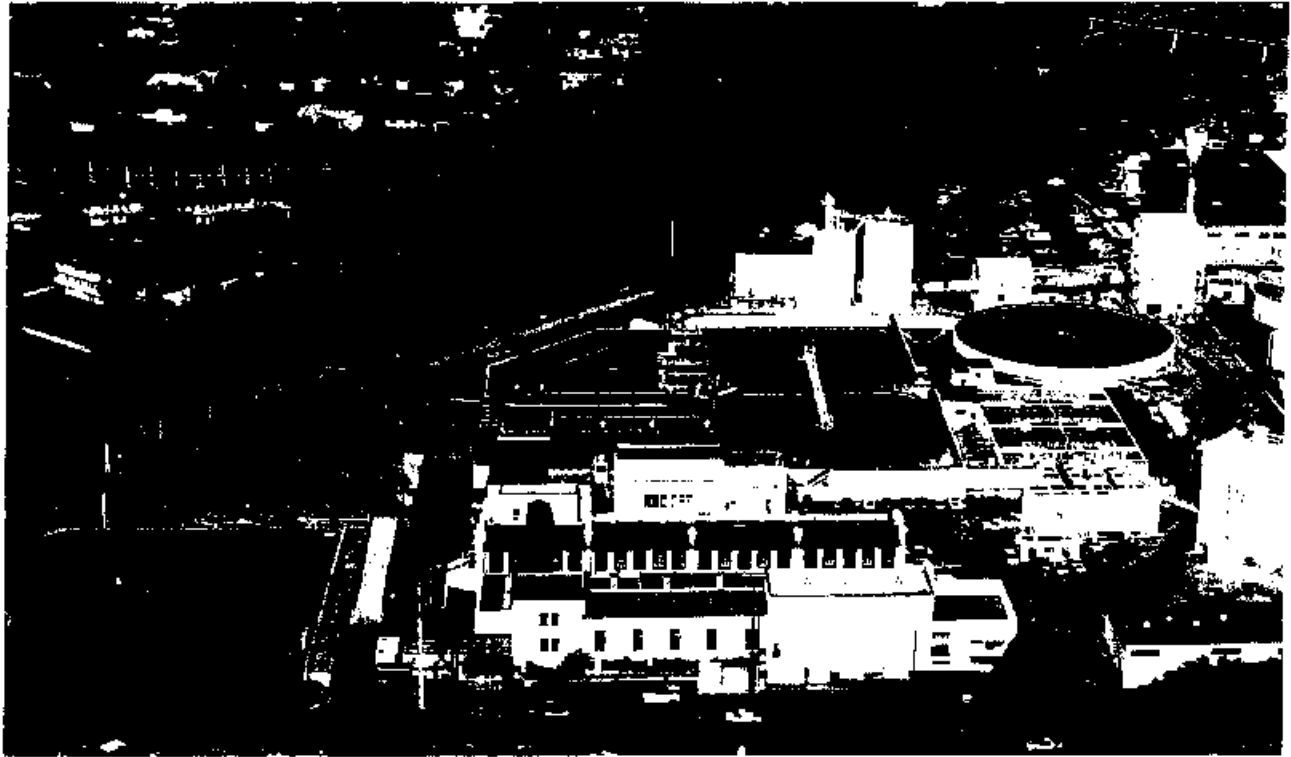
Use MD-100 for Enrichment O.H. Material Co. Figure.

FIGURE 11
E.P. Toxicity Results in Excess of 10 Times Standard

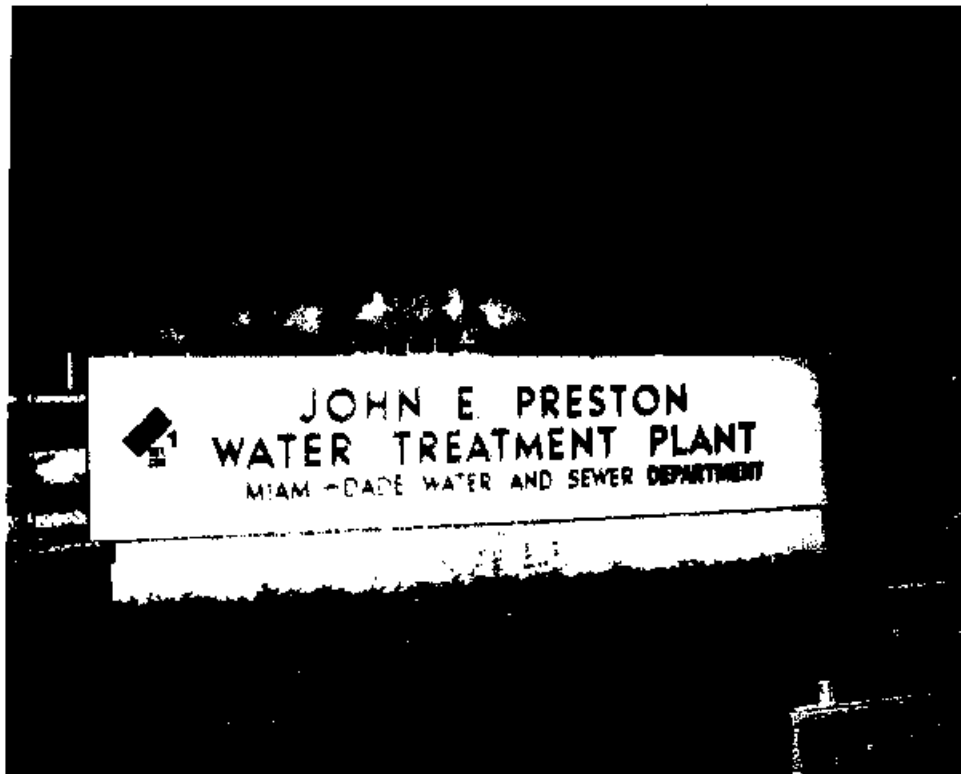


ATTACHMENT A

PHOTOGRAPHS



Hialeah Water Treatment Plant – View of 20 – 14 foot diameter air stripper towers



Entrance to John E. Preston Water Treatment Plant



Top view of 44 - 14 foot diameter air stripper towers at the Preston Water Treatment Plant



Preston Water Treatment Plant – Top of Air Stripper Tower showing mist eliminator



Preston Water Treatment Plant – Photograph noting four sampling stations for every quarter segment of an air stripper tower.



Miami Springs Pump Station No. 9 – View looking west. Pump station nearest to Miami Drum Services Site. Former Miami Drum Services Site is approximately ½ mile in the background.



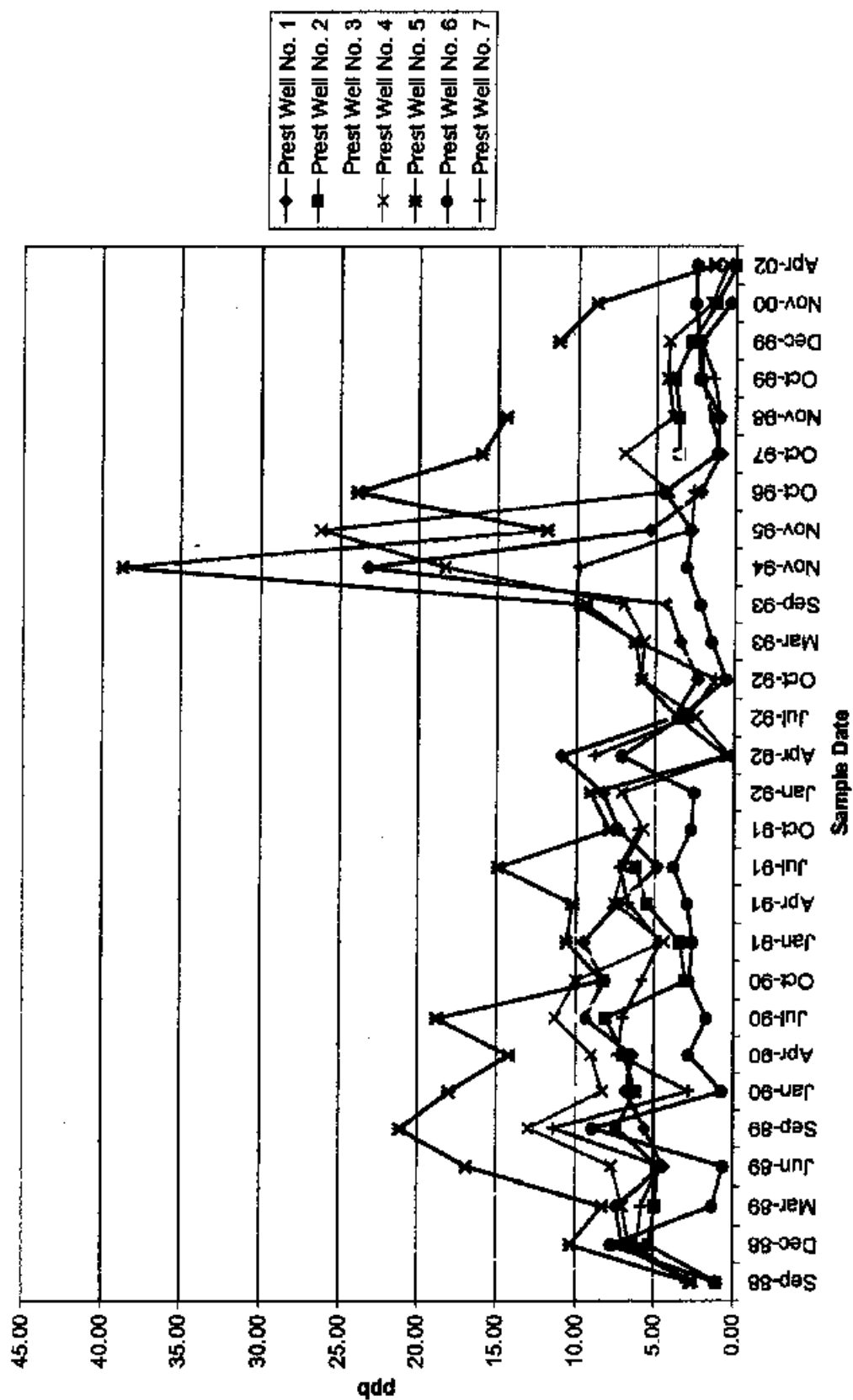
Miami Springs Pump Station No. 9 – Pump station nearest to Miami Drum Services Site.



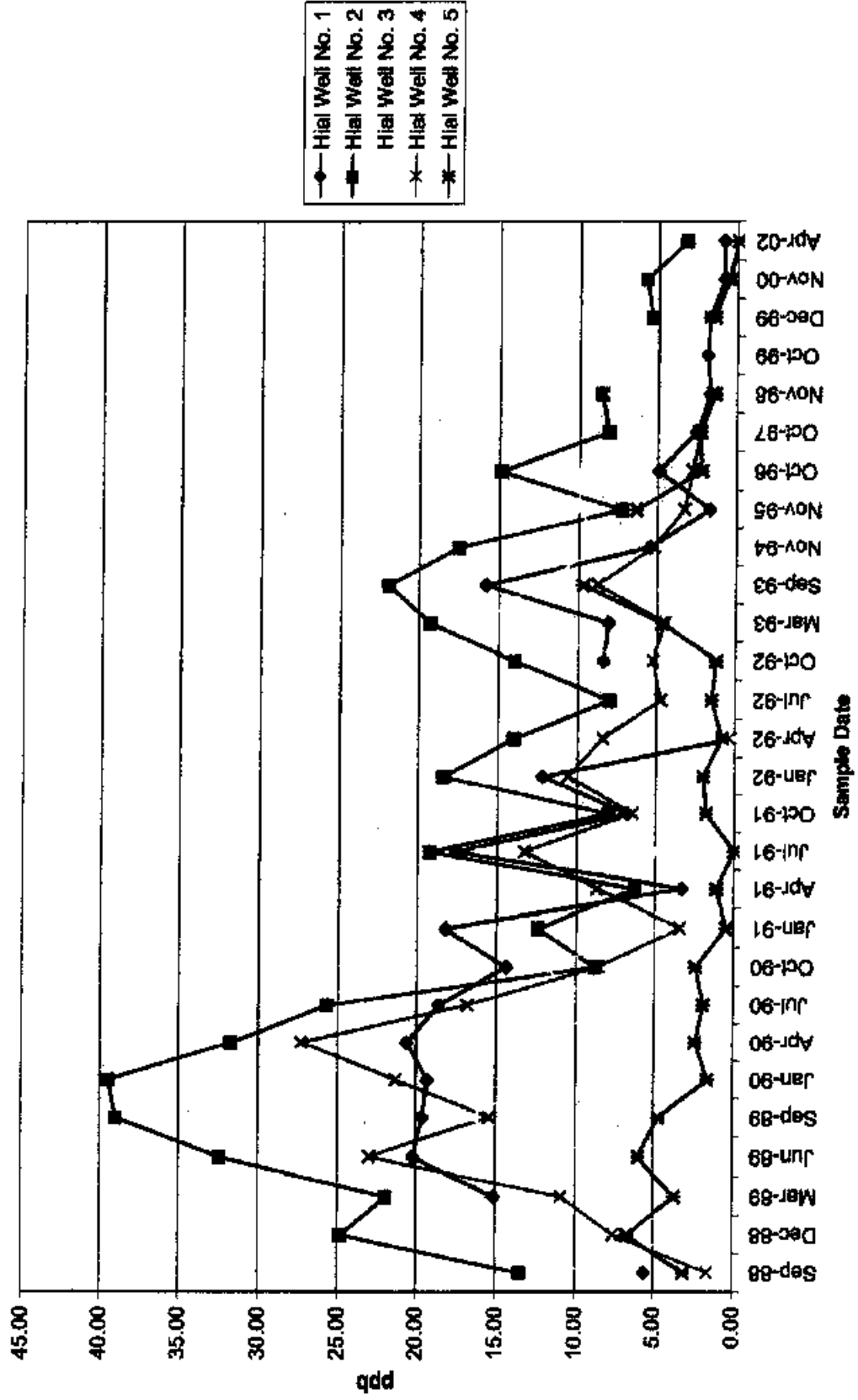
Panoramic View of Dade County Transit Operations and Maintenance Center. View taken from Miami Dairy Road looking east. Former Miami Drum Services Site is located in the center-right of the picture.

ATTACHMENT B

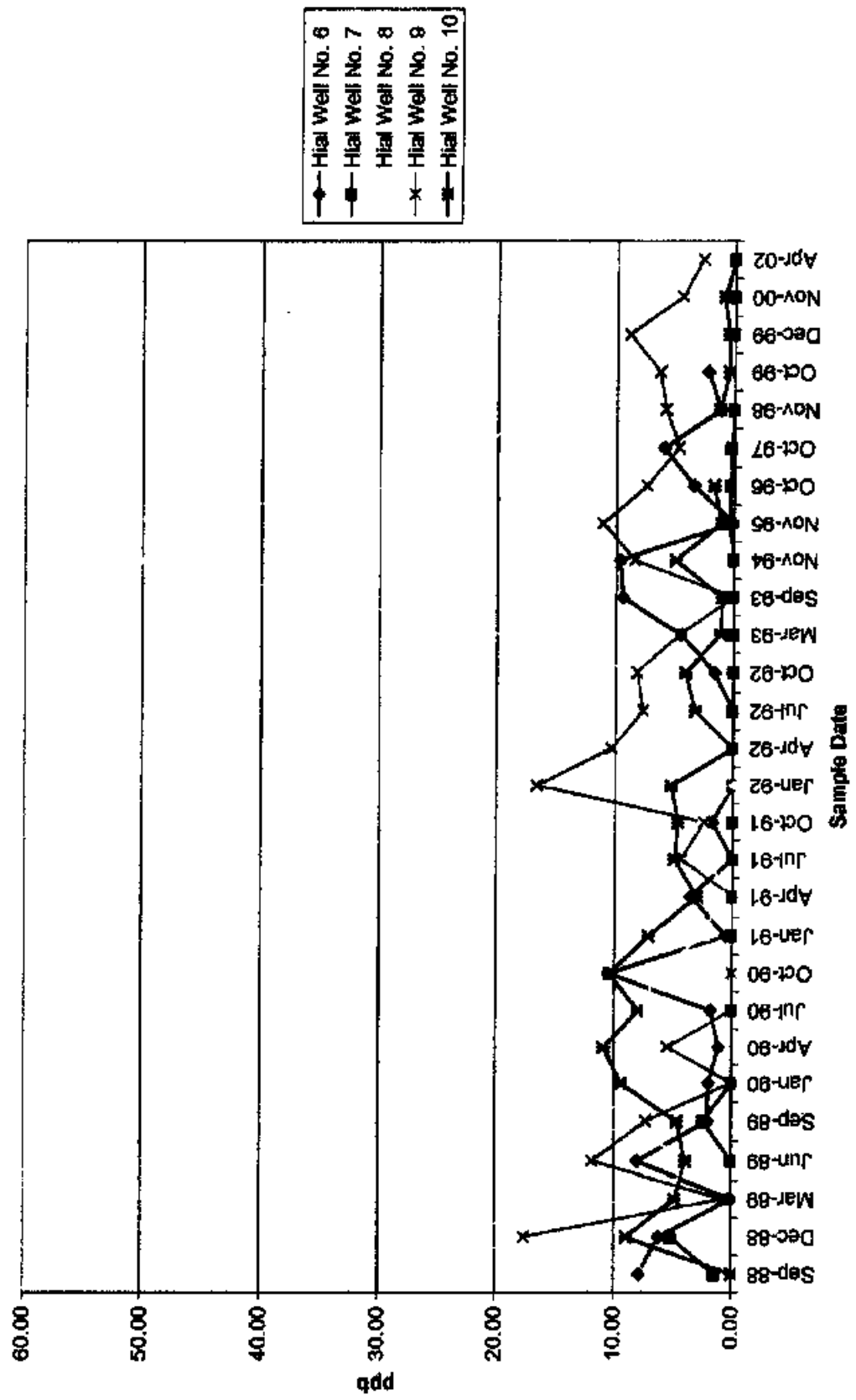
VOC CONCENTRATION TREND IN PRESTON & HIALEAH WELLS



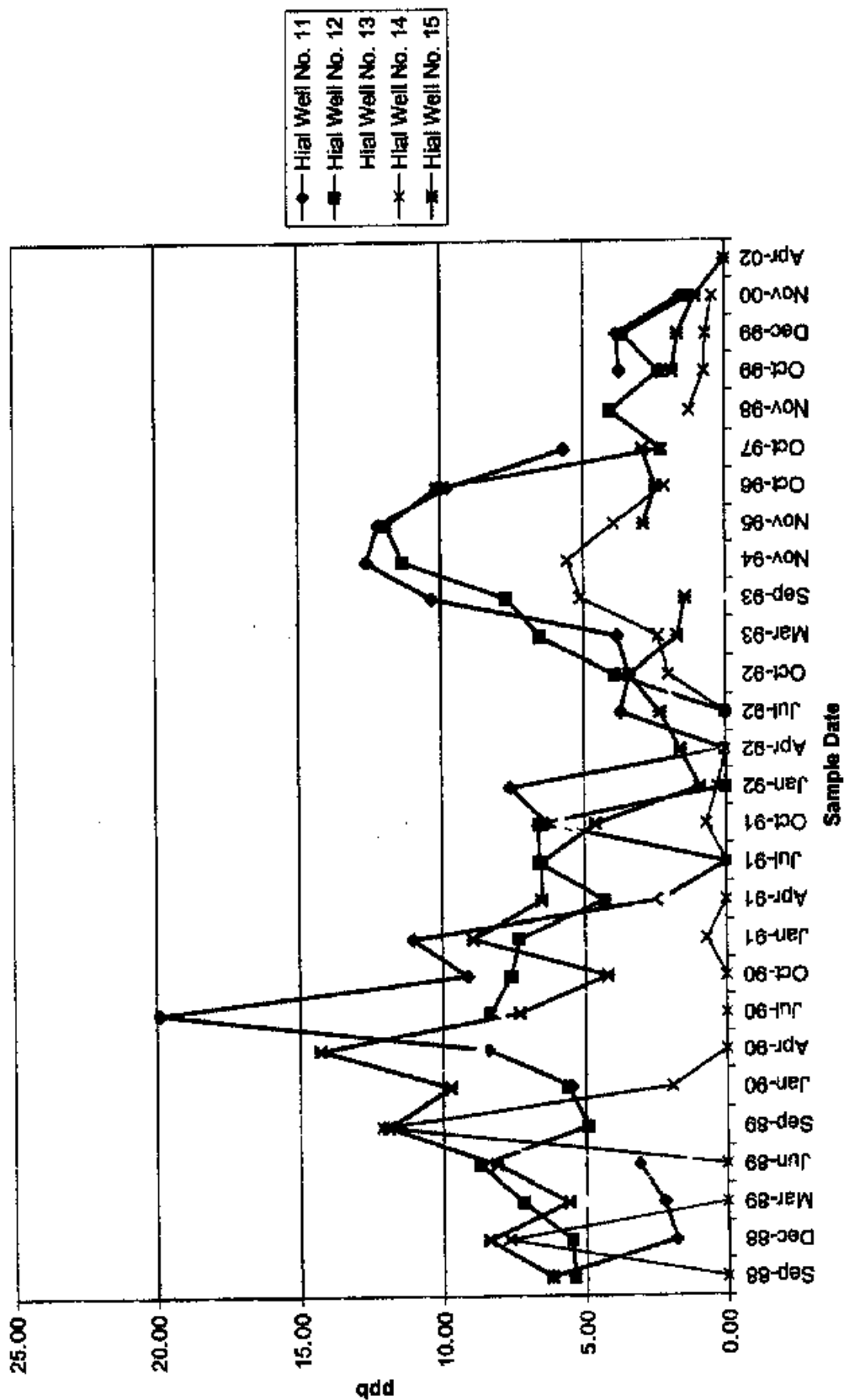
TOTAL VOC CONCENTRATION Hialeah Wells 1 through 5



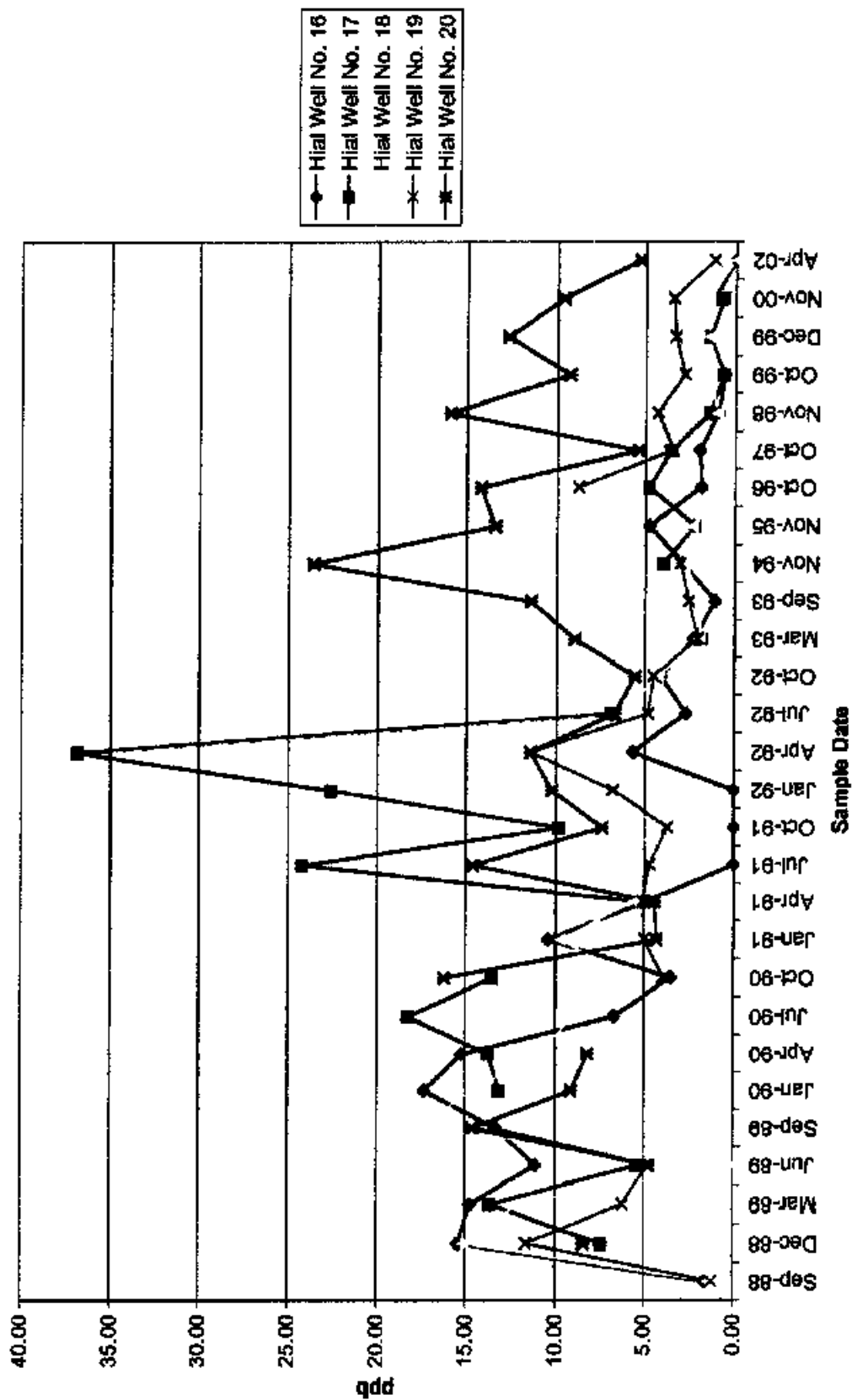
TOTAL VOC CONCENTRATION Hialeah Wells 6 through 10



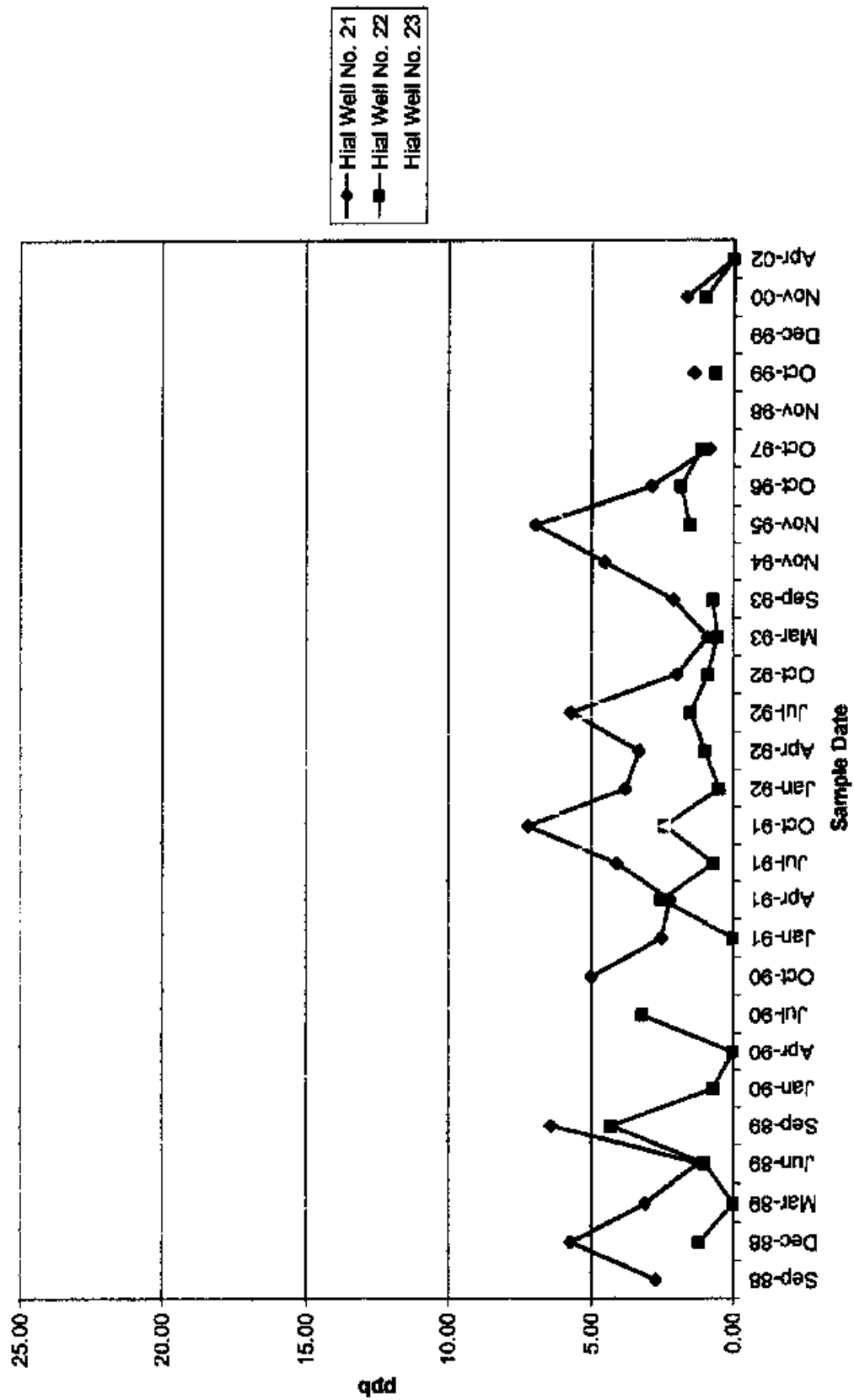
TOTAL VOC CONCENTRATION Hialeah Wells 11 through 15



TOTAL VOC CONCENTRATION Hialeah Wells 16 through 20



TOTAL VOC CONCENTRATION Haleah Wells 21 through 23



ATTACHMENT C

MONTHLY AIR EMISSIONS

Air Stripping Tower Pollutant Emissions
 12-Months - June 2001 to May 2002
 Miami-Dade Water and Sewer Department
 Hialeah & Preston Water Treatment Plants
 Facility I.D.: 0250281
 Permit Number: 0250281-005-AV

Pollutant ¹	Emission Limitation (tons/12-months) ¹	12-month Total Tons Emitted ²	Highest 12-month Total Tons Emitted ³
1,1-Dichloroethane	1.00	0.000	0.000
Vinyl Chloride	1.00	0.065	0.104
1,2-Dichloroethylene	1.00	0.000	0.000
Chloroform	40.00	15.145	15.145
Dichlorobromomethane	10.00	4.264	4.626
Chlorodibromomethane	3.00	1.113	1.157
Methylene Chloride	1.00	0.000	0.000
Trichloroethylene	1.00	0.000	0.000
THM's		20.542	20.542
VOC's		0.086	0.134
Total VOCs (including THMs)	59.00	20.628	20.628

Notes:

¹ Table 1, Operating Permit Number 0250281-005-AV

² Assumes all pollutants detected are emitted.

³ Value indicated does not have to equal total emitted during the reporting period.

--	--

¹ Monthly emissions (ton) = Σ monthly emissions (t/ton) \times Σ monthly emissions Fraction (ton)

² 12-months (annual) emissions (ton) = Σ monthly emissions (ton) (12 previous months)

³ Total VOCs entering the air stripping towers, as measured by EPA method 503.2

ATTACHMENT D

2001 VOC AND TTHM DATA FROM PRESTON AND HIALEAH WTP'S

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: February 21, 2001

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
January 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
01-03-01	BDL	1.43	16.5	1.36	5.91	BDL
01-09-01	BDL	1.31	11.4	1.03	13.1	BDL
01-11-01	BDL	0.83	12.6	1.17	10.4	BDL
01-17-01	BDL	2.49	12.7	2.43	11.2	BDL
01-19-01	BDL	1.56	14.1	1.42	9.47	BDL
01-23-01	BDL	1.16	12.3	1.62	6.81	BDL
01-25-01	---	---	12.4	0.66	6.45	BDL
01-26-01	BDL	1.13	---	---	---	---
01-30-01	BDL	0.85	5.53	BDL	6.78	BDL
AVERAGE	BDL	1.35	12.2	1.21	5.41	BDL
LOW	BDL	0.83	5.51	BDL	0.44	BDL
HIGH	BDL	2.49	16.6	2.43	13.1	BDL

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLUENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1 VENT. 2	VENT. 1	VENT. 2				
01-03-01	BDL	1.11	BDL	12.4	0.36	25.2	BDL
01-09-01	BDL	0.89	BDL	75.7	BDL	81.2	BDL
01-11-01	BDL	0.43	BDL	11.1	Trace	27.8	BDL
01-17-01	BDL	0.40	BDL	12.9	0.20	42.5	BDL
01-19-01	BDL	BDL	BDL	13.9	BDL	23.3	BDL
01-23-01	BDL	2.43	BDL	12.8	BDL	24.5	BDL
01-25-01	BDL	1.26	0.29	11.7	BDL	29.1	BDL
01-30-01	BDL	0.52	BDL	14.1	BDL	46.8	BDL
AVERAGE	BDL	0.88	BDL	12.1	BDL	16.1	BDL
LOW	BDL	BDL	BDL	75.7	BDL	27.8	BDL
HIGH	BDL	2.43	0.29	14.1	0.36	46.8	BDL

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: March 22, 2001

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
February 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
02-01-01	BDL	1.53	11.8	0.88	0.63	BDL
02-06-01	BDL	1.11	13.8	0.51	9.93	BDL
02-08-01	BDL	1.41	14.8	0.85	0.52	BDL
02-13-01	BDL	1.48	10.5	1.66	BDL	BDL
02-15-01	BDL	1.68	14.5	1.61	BDL	BDL
02-20-01	BDL	2.15	12.7	0.90	BDL	0.31
02-22-01	BDL	2.22	15.0	1.23	BDL	BDL
02-27-01	BDL	1.84	24.3	1.91	1.22	BDL
AVERAGE	BDL	1.68	14.7	1.19	3.41	BDL
LOW	BDL	1.11	10.5	0.51	BDL	BDL
HIGH	BDL	2.22	24.3	1.91	9.93	0.31

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLUENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1 VENT. 2	VENT. 1	VENT. 2				
02-01-01	BDL	1.50	0.20	13.8	0.61	42.6	BDL
02-06-01	BDL	0.54	Trace	12.2	0.23	38.0	BDL
02-08-01	BDL	BDL	BDL	15.1	BDL	58.1	BDL
02-13-01	BDL	1.03	BDL	17.9	0.39	27.0	BDL
02-15-01	BDL	0.91	BDL	14.6	0.37	54.9	BDL
02-20-01	BDL	0.28	Trace	11.0	0.34	42.9	BDL
02-22-01	BDL	1.18	0.48	11.7	0.66	45.7	BDL
02-27-01	BDL	1.03	0.43	12.3	0.54	52.8	BDL
AVERAGE	BDL	0.81	BDL	13.0	0.39	43.0	BDL
LOW	BDL	BDL	BDL	11.0	BDL	24.0	BDL
HIGH	BDL	1.50	0.48	15.1	0.66	58.1	BDL

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: April 20, 2001

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
March 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
03-01-01	BDL	2.40	1.65	2.38	BDL	BDL
03-06-01	BDL	2.66	2.38	0.77	BDL	BDL
03-08-01	BDL	1.32	1.8	0.72	BDL	BDL
03-13-01	BDL	1.35	1.3	0.94	BDL	BDL
03-15-01	BDL	1.24	1.0	0.58	BDL	BDL
03-20-01	BDL	2.18	1.54	1.52	BDL	BDL
03-22-01	BDL	1.44	2.5	---	0.24	BDL
03-27-01	BDL	1.39	2.5	2.42	BDL	BDL
03-29-01	BDL	1.34	1.5	1.40	BDL	BDL
AVERAGE	BDL	1.70	1.5	1.34	BDL	BDL
LOW	BDL	1.24	1.0	0.58	BDL	BDL
HIGH	BDL	2.66	2.5	2.42	0.24	BDL

TO: Tom Segars, Chief
Water Production Division

DATE: March 22, 2001

Results of VOC & TTHM Analyses
Page 2

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLU- ENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1	VENT. 1	VENT. 2				
03-01-01	BDL	0.68	BDL	1.24	0.20	59.6	BDL
03-06-01	BDL	BDL	BDL	1.31	BDL	52.7	BDL
03-08-01	BDL	BDL	BDL	1.25	BDL	56.2	BDL
03-13-01	BDL	BDL	BDL	1.46	BDL	49.2	BDL
03-15-01	BDL	BDL	BDL	1.35	BDL	41.9	BDL
03-20-01	BDL	0.22	BDL	1.14	BDL	55.1	BDL
03-22-01	BDL	0.69	BDL	---	---	42.2	BDL
03-27-01	BDL	2.73	BDL	1.13	0.74	46.7	BDL
03-29-01	BDL	0.95	BDL	---	---	54.1	BDL
AVERAGE	BDL	0.59	BDL	1.27	BDL	49.4	BDL
LOW	BDL	BDL	BDL	1.14	BDL	42.2	BDL
HIGH	BDL	2.73	BDL	1.46	0.74	59.6	BDL

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: May 14, 2001

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
April 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
04-04-01	BDL	1.46	15.8	1.45	0.53	BDL
04-06-01	BDL	1.62	26.2	1.13	BDL	BDL
04-11-01	BDL	0.75	13.2	0.58	BDL	BDL
04-13-01	BDL	0.86	22.8	0.66	1.56	BDL
04-17-01	BDL	1.25	16.1	0.89	BDL	BDL
04-19-01	BDL	1.82	13.5	1.00	BDL	BDL
04-24-01	BDL	1.46	15.5	0.72	BDL	BDL
04-26-01	BDL	1.90	15.1	1.92	BDL	BDL
AVERAGE	BDL	1.39	16.5	1.04	0.27	BDL
LOW	BDL	0.75	12.8	0.58	BDL	BDL
HIGH	BDL	1.90	26.2	1.92	1.56	BDL

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLUENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1/ VENT. 2	VENT. 1	VENT. 2				
04-04-01	BDL	1.48	0.20	116	0.66	37.4	BDL
04-06-01	BDL	1.19	BDL	112	0.79	38.0	BDL
04-11-01	BDL	0.70	TRACE	118	0.52	32.3	BDL
04-17-01	BDL	1.19	BDL	114	0.30	40.7	BDL
04-19-01	BDL	BDL	BDL	138	BDL	40.5	BDL
04-24-01	BDL	1.38	0.31	98.3	0.93	29.6	BDL
04-26-01	BDL	TRACE	BDL	138	0.57	40.2	BDL
AVERAGE	BDL	0.85	0.10	119	0.54	37.0	BDL
LOW	BDL	BDL	BDL	98.3	BDL	29.6	BDL
HIGH	BDL	1.48	0.31	138	0.93	40.9	BDL

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: June 18, 2001

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
May 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
05-01-01	BDL	1.31	21.3	0.26	BDL	BDL
05-03-01	BDL	0.94	13.7	1.00	BDL	BDL
05-08-01	BDL	0.90	14.8	1.21	BDL	BDL
05-10-01	BDL	1.00	13.1	1.73	BDL	BDL
05-15-01	BDL	1.42	14.0	1.54	BDL	BDL
05-17-01	BDL	0.56	14.5	1.32	0.45	BDL
05-22-01	BDL	2.29	19.5	0.89	0.27	BDL
05-24-01	BDL	2.11	18.2	1.34	BDL	BDL
05-30-01	BDL	2.46	15.8	1.37	BDL	BDL
AVERAGE	BDL	1.44	16.1	1.18	BDL	BDL
LOW	BDL	0.56	13.1	0.26	BDL	BDL
HIGH	BDL	2.46	21.3	1.73	0.45	BDL

TO: Tom Segars, Chief
Water Production Division

DATE: JUNE 18, 2001

Results of VOC & THM Analyses
Page 2

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLU- ENT		FINISH	
	THM	VOC	VOC	THM	VOC	THM	VOC
	VENT. 1/ VENT. 2	VENT. 1	VENT. 2				
05-01-01	BDL	0.55	Trace	114	0.58	35.8	BDL
05-03-01	BDL	0.66	BDL	127	0.29	36.3	BDL
05-08-01	BDL	0.82	BDL	139	0.20	31.9	BDL
05-10-01	BDL	0.80	BDL	116	Trace	33.6	BDL
05-15-01	BDL	BDL	BDL	114	0.43	36.5	BDL
05-17-01	BDL	Trace	Trace	121	0.28	43.3	BDL
05-22-01	BDL	0.38	BDL	---	---	48.1	BDL
05-24-01	BDL	1.05	0.44	92.7	BDL	48.8	BDL
05-30-01	BDL	1.00	0.36	103	0.80	61.4	BDL
AVERAGE	BDL	0.58	BDL	116	0.27	41.6	BDL
LOW	BDL	BDL	BDL	92.7	BDL	31.9	BDL
HIGH	BDL	1.05	0.44	139	0.80	61.4	BDL

MEMORANDUM

Tom Segars, Chief
Water Production Division

DATE: July 18, 2001

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (B56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
June 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
06-05-01	BDL	1.22	17.0	1.25	BDL	BDL
06-07-01	BDL	2.57	17.0	1.13	BDL	BDL
06-12-01	BDL	2.76	12.5	1.90	BDL	BDL
06-14-01	BDL	0.97	18.3	1.76	BDL	BDL
06-19-01	BDL	0.46	32.3	1.41	BDL	BDL
06-21-01	BDL	0.53	21.2	1.08	20.0	BDL
06-26-01	BDL	1.26	18.2	1.93	Trace	BDL
06-28-01	BDL	1.15	18.3	1.52	17.0	BDL
AVERAGE	BDL	1.37	19.4	1.50	4.63	BDL
LOW	BDL	0.46	12.5	1.08	BDL	BDL
HIGH	BDL	2.76	32.3	1.93	20.0	BDL

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLUENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1/ VENT. 2	VENT. 1	VENT. 2				
06-05-01	BDL	0.82	BDL	123	0.38	37.8	BDL
06-07-01	BDL	1.01	0.26	115	0.57	36.3	BDL
06-12-01	BDL	0.79	0.26	113	BDL	66.6	BDL
06-14-01	BDL	0.32	BDL	125	BDL	40.8	BDL
06-19-01	BDL	0.77	BDL	121	BDL	42.5	BDL
06-21-01	BDL	1.10	BDL	117	BDL	36.1	BDL
06-26-01	BDL	1.07	BDL	109	0.47	37.9	BDL
06-28-01	BDL	0.94	BDL	110	0.38	37.1	BDL
AVERAGE	BDL	0.86	BDL	117	0.23	41.9	BDL
LOW	BDL	0.32	BDL	109	BDL	36.1	BDL
HIGH	BDL	1.10	0.26	125	0.57	66.6	BDL

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: August 24, 2001

FROM: Martha Andollo
Chemist 2
Orx Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
July 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
07-03-01	BDL	1.22	21.3	1.39	Trace	BDL
07-05-01	BDL	0.88	21.6	1.91	Trace	BDL
07-10-01	BDL	2.55	21.0	2.17	6.11	BDL
07-12-01	BDL	2.44	20.5	2.16	0.28	BDL
07-17-01	BDL	2.67	31.4	1.77	0.44	BDL
07-19-01	BDL	1.43	16.2	1.73	Trace	BDL
07-24-01	BDL	1.93	26.1	1.14	2.21	BDL
07-26-01	BDL	0.91	15.3	2.09	Trace	BDL
07-31-01	BDL	1.17	12.2	1.12	Trace	BDL
AVERAGE	BDL	1.69	20.6	1.72	1.78	BDL
LOW	BDL	0.88	12.2	1.12	Trace	BDL
HIGH	BDL	2.67	31.4	2.16	6.11	BDL

TO: Tom Segars, Chief
Water Production Division

DATE: August 24, 2001

Results of VOC & TTHM Analyses
Page 2

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLU- ENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1 VENT. 2	VENT. 1	VENT. 2				
07-03-01	BDL	0.97	BDL	125	0.47	32.7	BDL
07-05-01	BDL	1.09	BDL	116	0.56	34.9	BDL
07-10-01	BDL	1.48	0.30	125	0.54	40.2	BDL
07-12-01	BDL	1.25	BDL	101	0.76	46.5	BDL
07-17-01	BDL	1.05	BDL	138	0.52	44.5	BDL
07-19-01	BDL	1.02	BDL	139	BDL	44.0	BDL
07-19-01	BDL	1.02	1.60	88.3	BDL	32.8	BDL
07-24-01	BDL	Trace	BDL	126	BDL	45.6	BDL
07-26-01	BDL	BDL	2.97	129	BDL	49.1	BDL
07-31-01	BDL						
AVERAGE	BDL	0.88	0.54	121	0.32	42.0	BDL
LOW	BDL	BDL	BDL	88.3	BDL	32.8	BDL
HIGH	BDL	1.48	2.97	138	0.76	49.1	BDL

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: September 24, 2001

FROM: Martha Andollo
Chemist 2

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
August 2001

Orr Water Quality Laboratory (E56720)

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
08-02-01	BDL	0.84	11.1	1.13	BDL	BDL
08-16-01	BDL	0.45	13.8	0.39	BDL	BDL
08-21-01	BDL	0.32	8.16	0.24	3.53	BDL
08-23-01	BDL	Trace	5.37	BDL	BDL	BDL
08-28-01	BDL	1.86	11.2	1.04	BDL	1.03
08-30-01	BDL	1.84	9.71	BDL	12.7	BDL
AVERAGE	BDL	0.89	9.89	0.47	2.72	0.17
LOW	BDL	Trace	8.16	BDL	Trace	BDL
HIGH	BDL	1.84	13.8	1.13	12.7	1.03

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLUENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1/ VENT. 2	VENT. 1	VENT. 2				
08-02-01	BDL	0.88	0.94	109	0.84	41.4	BDL
08-16-01	BDL	0.67	BDL	83.3	0.22	28.5	BDL
08-21-01	BDL	0.32	BDL	---	---	29.8	BDL
08-23-01	BDL	Trace	BDL	---	---	26.4	BDL
08-28-01	BDL	1.30	0.40	133	BDL	43.9	BDL
08-30-01	BDL	1.16	0.32	150	BDL	41.4	BDL
AVERAGE	BDL	0.72	0.28	119	0.27	28.5	BDL
LOW	BDL	Trace	BDL	83.3	BDL	26.4	BDL
HIGH	BDL	1.30	9.40	150	0.84	41.1	BDL

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: October 30, 2001

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (B56720)

SUBJECT: Results of VOC & THM
Analyses from Hialeah,
Preston & Orr WTPs
September 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
		VOC		VOC		VOC
09-04-01		0.73		0.43		BDL
09-11-01		1.64		1.70		BDL
09-13-01		0.42		BDL		BDL
09-19-01		1.07		0.46		BDL
09-25-01		2.04		---		BDL
09-27-01		2.19		---		BDL
AVERAGE		1.35		0.71		BDL
LOW		0.42		BDL		BDL
HIGH		2.19		1.70		BDL

PRESTON WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
		VOC	VOC		VOC	VOC
		VENT. 1	VENT. 2			
09-04-01		0.45	BDL		BDL	BDL
09-11-01		0.95	---		1.59	0.24
09-13-01		BDL	BDL		BDL	BDL
09-19-01		0.69	BDL		BDL	BDL
09-25-01		1.33	0.38		0.36	BDL
09-27-01		1.44	0.71		0.36	BDL
AVERAGE		0.81	0.22		0.39	BDL
LOW		BDL	BDL		BDL	BDL
HIGH		1.44	0.71		1.59	0.24

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: November 28, 2001

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Haleah,
Preston & Orr WTPs
October 2001

HALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
		VOC		VOC		VOC
10-09-01		0.45		0.47		BDL
10-11-01		0.96		0.52		BDL
10-15-01		0.93		0.38		BDL
10-23-01		1.11		0.41		BDL
10-25-01		1.65		0.94		BDL
AVERAGE		1.02		0.54		BDL
LOW		0.45		0.38		BDL
HIGH		1.65		0.94		BDL

PRESTON WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
		VOC	VOC		VOC	VOC
		VENT. 1	VENT. 2			
10-09-01		BDL	---		BDL	BDL
10-11-01		1.31	0.26		BDL	BDL
10-15-01		Trace	BDL		0.29	Trace
10-23-01		Trace	BDL		0.49	BDL
10-25-01		1.31	0.34		0.63	BDL
AVERAGE		1.12	0.15		0.29	BDL
LOW		BDL	BDL		BDL	BDL
HIGH		1.31	0.34		0.63	Trace

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: January 2, 2002

FROM: Martha Andollo
Chemist 2
Ort Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
November 2001

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
11-06-01	BDL	2.10	12.0	1.62	0.88	BDL
11-08-01	BDL	2.35	10.9	1.78	1.74	BDL
11-13-01	BDL	1.78	6.64	1.43	BDL	BDL
11-16-01	BDL	1.89	7.39	1.32	BDL	BDL
11-20-01	BDL	1.94	7.77	1.52	BDL	BDL
11-27-01	BDL	1.82	42.1	BDL	8.97	BDL
AVERAGE	BDL	1.98	14.5	1.28	3.10	BDL
LOW	BDL	1.78	6.64	BDL	BDL	BDL
HIGH	BDL	2.35	42.1	1.78	8.97	BDL

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER INFLUENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1/ VENT. 2	VENT. 1	VENT. 2				
11-06-01	BDL	1.20	0.38	143	0.75	39.7	BDL
11-08-01	BDL	1.58	0.36	134	0.51	43.4	BDL
11-13-01	BDL	1.15	0.20	119	0.31	42.4	BDL
11-16-01	BDL	0.70	BDL	135	0.24	47.7	BDL
11-20-01	BDL	1.28	0.22	119	0.40	42.3	BDL
11-27-01	BDL	1.10	0.23	125	0.73	31.1	BDL
AVERAGE	BDL	1.17	0.23	129	0.49	41.1	BDL
LOW	BDL	0.70	BDL	119	0.24	39.7	BDL
HIGH	BDL	1.58	0.38	143	0.75	47.7	BDL

MEMORANDUM

TO: Tom Segars, Chief
Water Production Division

DATE: January 23, 2002

FROM: Martha Andollo
Chemist 2
Orr Water Quality Laboratory (E56720)

SUBJECT: Results of VOC & TTHM
Analyses from Hialeah,
Preston & Orr WTPs
December 2001

REVISED

HIALEAH WATER TREATMENT PLANT

DATE	RAW		TOWER INFLUENT		FINISH	
	TTHM	VOC	TTHM	VOC	TTHM	VOC
12-04-01	BDL	2.0	**	**	14.8	BDL
12-06-01	BDL	2.05	17.4	1.27	5.52	BDL
12-27-01*	BDL	BDL	BDL	BDL	BDL	BDL
AVERAGE	BDL	1.35	10.6	0.69	6.77	BDL
LOW	BDL	BDL	BDL	BDL	BDL	BDL
HIGH	BDL	2.05	17.4	1.27	14.8	BDL

PRESTON WATER TREATMENT PLANT

DATE	RAW			TOWER IN- FLUENT		FINISH	
	TTHM	VOC	VOC	TTHM	VOC	TTHM	VOC
	VENT. 1/ VENT. 2	VENT. 1	VENT. 2				
12-04-01	BDL	0.98	0.22	121	0.31	46.6	BDL
12-06-01	BDL	0.89	0.38	122	BDL	41.9	BDL
12-27-01*	BDL	BDL	BDL	BDL	BDL	BDL	BDL
AVERAGE	BDL	0.62	0.30	81	BDL	30.2	BDL
LOW	BDL	BDL	BDL	BDL	BDL	BDL	BDL
HIGH	BDL	0.98	0.38	122	0.31	46.6	BDL

ATTACHMENT E

2001 OPERATION RECORDS FOR HIALEAH, PRESTON, MIAMI SPRINGS, AND NORTHWEST WELLFIELD WELLS

[illegible]

HUALFAN					TOTAL WELL M/G
28	29	30	31		
4.987	4.875	4.638	4.785		54.8
0.000	0.000	0.000	0.000		28.0
0.000	0.000	0.000	0.000		42.9
4.183	4.185	3.883	4.007		108.2
0.000	0.000	0.000	0.000		58.2
0.000	0.000	0.000	0.000		88.2
0.000	0.000	0.000	0.000		24.7
0.000	0.000	0.000	0.000		57.7
4.185	4.185	3.883	4.007		91.4
0.000	0.000	0.000	0.000		28.0
0.000	0.000	0.000	0.000		10.8
0.000	0.000	0.000	0.000		15.1
5.972	5.942	6.472	6.675		87.1
4.183	4.185	3.883	4.007		89.7
0.000	0.000	0.000	0.000		84.9
4.183	0.000	0.000	4.007		61.3
0.000	0.000	0.000	0.000		87.8
0.000	0.000	0.000	0.000		93.0
0.000	0.000	0.000	0.000		75.2
4.183	4.185	3.883	4.007		102.2
4.183	4.185	3.883	4.007		100.8
0.000	0.000	0.000	0.000		87.0
0.000	0.000	0.000	0.000		104.7
0.000	0.000	0.000	0.000		86.2
0.000	0.000	0.000	0.000		56.4
0.000	0.000	5.383	11.131		96.9
11.621	11.571	5.383	0.000		124.5
0.000	0.000	10.786	11.131		37.9
11.621	11.571	5.383	0.000		107.2
0.000	0.000	5.383	5.957		28.2
0.000	0.000	5.383	0.000		189.7
0.000	0.000	5.383	0.000		0.0
0.000	0.000	5.383	11.131		53.8
0.000	0.000	0.000	0.000		86.3
0.000	0.000	0.000	0.000		0.0
0.000	0.000	0.000	0.000		0.0
0.000	11.571	5.383	0.000		200.4
0.000	0.000	0.000	0.000		0.0
11.621	0.000	5.383	11.131		235.4
0.000	0.000	0.000	0.000		0.0
11.621	11.571	5.383	0.000		123.4
0.000	0.000	0.000	0.000		0.0
11.621	11.571	5.383	0.000		159.2
0.000	0.000	0.000	0.000		159.2
11.621	11.571	5.383	0.000		0.0
0.000	0.000	0.000	0.000		123.2
11.621	11.571	10.786	11.131		228.2
0.000	0.000	0.000	0.000		0.0
0.000	0.000	5.383	11.131		183.0
0.000	0.000	0.000	0.000		0.0
0.000	0.000	0.000	0.000		210.6
0.000	0.000	0.000	0.000		0.0
11.621	11.571	5.383	0.000		233.4
0.000	0.000	0.000	0.000		0.0
0.000	0.000	0.000	0.000		69.3
0.000	0.000	0.000	0.000		0.0
0.000	0.000	5.383	11.131		183.6
0.000	0.000	0.000	0.000		0.0
138.1	134.5	139.3	144.2		4506.7
88.13	45.94	42.82	48.28		1474.41
87.35	89.59	75.57	73.74		2445.81
11.62	11.57	21.57	22.26		586.48

HALEAH					TOTAL WELL HOURS
24	29	30	31		
24.0	24.0	24.0	24.0		272
0.0	0.0	0.0	0.0		185
0.0	0.0	0.0	0.0		265
24.0	24.0	24.0	24.0		653
24.0	24.0	24.0	24.0		353
0.0	0.0	0.0	0.0		192
0.0	0.0	0.0	0.0		201
0.0	0.0	0.0	0.0		337
0.0	24.0	24.0	24.0		543
24.0	24.0	24.0	24.0		200
0.0	0.0	0.0	0.0		59
0.0	0.0	0.0	0.0		59
0.0	0.0	0.0	0.0		79.5
24.0	24.0	24.0	24.0		248
24.0	24.0	24.0	24.0		537.5
0.0	0.0	0.0	0.0		500
24.0	0.0	0.0	24.0		367
0.0	0.0	0.0	0.0		517
0.0	0.0	0.0	0.0		544
0.0	0.0	0.0	0.0		440.5
24.0	24.0	24.0	24.0		809
24.0	24.0	24.0	24.0		500
24.0	24.0	24.0	24.0		578
0.0	0.0	0.0	0.0		218.5
0.0	0.0	0.0	0.0		224
0.0	0.0	0.0	0.0		141
0.0	0.0	0.0	0.0		120.5
0.0	0.0	12.0	24.0		204
24.0	24.0	12.0	0.0		268.5
0.0	0.0	24.0	24.0		85
24.0	24.0	12.0	0.0		231
0.0	0.0	0.0	0.0		39.5
0.0	0.0	12.0	18.0		407
0.0	0.0	0.0	0.0		0
0.0	0.0	12.0	24.0		198.3
0.0	0.0	0.0	0.0		132
0.0	0.0	0.0	0.0		0
0.0	0.0	0.0	0.0		0
0.0	24.0	12.0	0.0		425
0.0	0.0	0.0	0.0		0
24.0	0.0	0.0	0.0		0
24.0	0.0	12.0	24.0		505
0.0	0.0	0.0	0.0		0
24.0	24.0	12.0	0.0		268
0.0	0.0	0.0	0.0		0
24.0	24.0	12.0	0.0		343
0.0	0.0	0.0	0.0		0
24.0	24.0	12.0	0.0		288.5
0.0	0.0	0.0	0.0		0
24.0	24.0	24.0	24.0		487.5
0.0	0.0	0.0	0.0		0
0.0	0.0	12.0	24.0		344
0.0	0.0	0.0	0.0		0
0.0	0.0	12.0	24.0		451.5
0.0	0.0	0.0	0.0		0
24.0	24.0	12.0	0.0		493.5
0.0	0.0	0.0	0.0		0
0.0	0.0	0.0	0.0		147
0.0	0.0	0.0	0.0		0
0.0	0.0	12.0	24.0		411.5
0.0	0.0	0.0	0.0		0
432.0	432.0	436.0	471.0		14,673.3
139.1	139.5	139.9	144.2		4,506.7

ATTACHMENT F

DOCUMENTS REVIEWED

Phase I -- Evaluation of the Clean-up Activities Already Undertaken at the Miami Drum Services Hazardous Waste Site, Dade County, Florida, CH2M Hill, 1982.

Superfund Record of Decision: Biscayne, Aquifer Sites, FI (EPA ROD RO4-85-004)

Phase II -- Sampling, Analytical, and Investigative Program for the Protection of the Biscayne Aquifer and Environment in North Dade County, Florida, CH2M Hill, 1984.

Remedial Investigation for Miami Drum Services Site, Florida, Florida Department of Environmental Regulation, November 1983.

Geophysical and Hydrogeological Investigation of the Miami Drum Site, Technos, Inc. February, 1983.

Record of Decision for the Miami Drum Services Site, Dade County, Florida, September 13, 1982.

Field Investigations of Uncontrolled Hazardous Waste Sites, FIT Project, Ecology and Environment, Inc. December, 1981.

Phase III -- Feasibility of Remedial Actions for the Protection of the Biscayne Aquifer in Dade County, Florida, CH2M Hill, May, 1995.

Draft Water Facility Master Plan, CH2M Hill, March 2000.

ATTACHMENT G

OVERVIEW OF THE TECHNICAL PROTOCOL FOR NATURAL ATTENUATION OF CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER UNDER DEVELOPMENT FOR THE U.S. AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLANCE

Overview of the Technical Protocol for Natural Attenuation of Chlorinated Aliphatic Hydrocarbons in Ground Water Under Development for the U.S. Air Force Center for Environmental Excellence

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Introduction

In the past several years, natural attenuation has become increasingly accepted as a remedial alternative for organic compounds dissolved in ground water. The U.S. Environmental Protection Agency's (EPA) Office of Research and Development and Office of Solid Waste and Emergency Response define natural attenuation as:

The biodegradation, dispersion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

In practice, natural attenuation has several other names, such as intrinsic remediation, intrinsic bioremediation, or passive bioremediation. The goal of any site characterization effort is to understand the fate and transport of the contaminants of concern over time in order to assess any current or potential threat to human health or the environment. Natural attenuation processes, such as biodegradation, can often be dominant factors in the fate and transport of contaminants. Thus, consideration and quantification of natural attenuation is essential to more thoroughly understand contaminant fate and transport.

This paper presents a technical protocol for data collection and analysis in support of remediation by natural attenuation to restore ground water contaminated with chlorinated aliphatic hydrocarbons and ground water

contaminated with mixtures of fuels and chlorinated aliphatic hydrocarbons. In some cases, the information collected using this protocol will show that natural attenuation processes, with or without source removal, will reduce the concentrations of these contaminants to below risk-based corrective action criteria or regulatory standards before potential receptor exposure pathways are completed. The evaluation should include consideration of existing exposure pathways as well as exposure pathways arising from potential future use of the ground water.

This protocol is intended to be used within the established regulatory framework. It is not the intent of this document to replace existing EPA or state-specific guidance on conducting remedial investigations.

Overview of the Technical Protocol

Natural attenuation in ground-water systems results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Biodegradation is the most important destructive attenuation mechanism. Nondestructive attenuation mechanisms include sorption, dispersion, dilution from recharge, and volatilization. The natural attenuation of fuel hydrocarbons is described in the *Technical Protocol for Implementing Intrinsic Remediation With Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater*, recently published by the U.S. Air Force Center for Environmental

Excellence (AFCEE) (1). This document differs from the technical protocol for intrinsic remediation of fuel hydrocarbons because the individual processes of chlorinated aliphatic hydrocarbon biodegradation are fundamentally different from the processes involved in the biodegradation of fuel hydrocarbons.

For example, biodegradation of fuel hydrocarbons, especially benzene, toluene, ethylbenzene, and xylenes (BTEX), is mainly limited by electron acceptor availability, and biodegradation of these compounds generally will proceed until all of the contaminants are destroyed. In the experience of the authors, there appears to be an inexhaustible supply of electron acceptors in most, if not all, hydrogeologic environments. On the other hand, the more highly chlorinated solvents (e.g., perchloroethene and trichloroethene) typically are biodegraded under natural conditions via reductive dechlorination, a process that requires both electron acceptors (the chlorinated aliphatic hydrocarbons) and an adequate supply of electron donors. Electron donors include fuel hydrocarbons or other types of anthropogenic carbon (e.g., landfill leachate, BTEX, or natural organic carbon). If the subsurface environment is depleted of electron donors before the chlorinated aliphatic hydrocarbons are removed, reductive dechlorination will cease, and natural attenuation may no longer be protective of human health and the environment. This is the most significant difference between the processes of fuel hydrocarbon and chlorinated aliphatic hydrocarbon biodegradation.

For this reason, it is more difficult to predict the long-term behavior of chlorinated aliphatic hydrocarbon plumes than fuel hydrocarbon plumes. Thus, it is important to have a thorough understanding of the operant natural attenuation mechanisms. In addition to having a better understanding of the processes of advection, dispersion, dilution from recharge, and sorption, it is necessary to better quantify biodegradation. This requires a thorough understanding of the interactions between chlorinated aliphatic hydrocarbons, anthropogenic/natural carbon, and inorganic electron acceptors at the site. Detailed site characterization is required to adequately understand these processes.

Chlorinated solvents are released into the subsurface under two possible scenarios: 1) as relatively pure solvent mixtures that are more dense than water, or 2) as mixtures of fuel hydrocarbons and chlorinated aliphatic hydrocarbons which, depending on the relative proportion of each, may be more or less dense than water. These products commonly are referred to as "nonaqueous-phase liquids," or NAPLs. If the NAPL is more dense than water, the material is referred to as a "dense nonaqueous-phase liquid," or DNAPL. If the NAPL is less dense than water, the material is referred to as a "light nonaqueous-phase liquid," or LNAPL. In general, the greatest mass of contaminant is associated

with these NAPL source areas, not with the aqueous phase.

As ground water moves through or past the NAPL source areas, soluble constituents partition into the moving ground water to generate a plume of dissolved contamination. After further releases have been stopped, these NAPL source areas tend to slowly weather away as the soluble components, such as BTEX or trichloroethene, are depleted. In cases where source removal or reduction is feasible, it is desirable to remove product and decrease the time required for complete remediation of the site. At many sites, however, mobile NAPL removal is not feasible with available technology. In fact, the quantity of NAPL recovered by commonly used recovery techniques is a trivial fraction of the total NAPL available to contaminate ground water. Mobile NAPL recovery typically recovers less than 10 percent of the total NAPL mass in a spill.

Compared with conventional engineered remediation technologies, natural attenuation has the following advantages:

- During natural attenuation, contaminants are ultimately transformed to innocuous byproducts (e.g., carbon dioxide, ethene, and water), not just transferred to another phase or location in the environment.
- Natural attenuation is nonintrusive and allows continuing use of infrastructure during remediation.
- Engineered remedial technologies can pose greater risk to potential receptors than natural attenuation because contaminants may be transferred into the atmosphere during remediation activities.
- Natural attenuation is less costly than currently available remedial technologies, such as pump-and-treat.
- Natural attenuation is not subject to the limitations of mechanized remediation equipment (e.g., no equipment downtime).
- Those compounds that are the most mobile and toxic are generally the most susceptible to biodegradation.

Natural attenuation has the following limitations:

- Natural attenuation is subject to natural and anthropogenic changes in local hydrogeologic conditions, including changes in ground-water gradients and velocity, pH, electron acceptor concentrations, electron donor concentrations, and/or potential future contaminant releases.
- Aquifer heterogeneity may complicate site characterization and quantification of natural attenuation.
- Time frames for complete remediation may be relatively long.

- Intermediate products of biodegradation (e.g., vinyl chloride) can be more toxic than the original contaminant.

This document describes those processes that bring about natural attenuation, the site characterization activities that may be performed to support a feasibility study to include an evaluation of natural attenuation, natural attenuation modeling using analytical or numerical solute fate-and-transport models, and the post-modeling activities that should be completed to ensure successful support and verification of natural attenuation. The objective of the work described herein is to quantify and provide defensible data in support of natural attenuation at sites where naturally occurring subsurface attenuation processes are capable of reducing dissolved chlorinated aliphatic hydrocarbon and/or fuel hydrocarbon concentrations to acceptable levels. A comment made by a member of the regulatory community (2) summarizes what is required to successfully implement natural attenuation:

A regulator looks for the data necessary to determine that a proposed treatment technology, if properly installed and operated, will reduce the contaminant concentrations in the soil and water to legally mandated limits. In this sense the use of biological treatment systems calls for the same level of investigation, demonstration of effectiveness, and monitoring as any conventional [remediation] system.

To support remediation by natural attenuation, the proponent must scientifically demonstrate that degradation of site contaminants is occurring at rates sufficient to be protective of human health and the environment. Three lines of evidence can be used to support natural attenuation of chlorinated aliphatic hydrocarbons, including:

- Observed reduction in contaminant concentrations along the flow path downgradient from the source of contamination.
- Documented loss of contaminant mass at the field scale using:
 - Chemical and geochemical analytical data (e.g., decreasing parent compound concentrations, increasing daughter compound concentrations, depletion of electron acceptors and donors, and increasing metabolic byproduct concentrations).
 - A conservative tracer and a rigorous estimate of residence time along the flow path to document contaminant mass reduction and to calculate biological decay rates at the field scale.
- Microbiological laboratory data that support the occurrence of biodegradation and give rates of biodegradation.

* a minimum, the investigator must obtain the first two lines of evidence or the first and third lines of evidence. The second and third lines of evidence are crucial to the

natural attenuation demonstration because they provide biodegradation rate constants. These rate constants are used in conjunction with the other fate-and-transport parameters to predict contaminant concentrations and to assess risk at downgradient points of compliance.

The first line of evidence is simply an observed reduction in the concentration of released contaminants downgradient from the NAPL source area along the groundwater flow path. This line of evidence does not prove that contaminants are being destroyed because the reduction in contaminant concentration could be the result of advection, dispersion, dilution from recharge, sorption, and volatilization with no loss of contaminant mass (i.e., the majority of apparent contaminant loss could be due to dilution). Conversely, an increase in the concentrations of some contaminants, most notably degradation products such as vinyl chloride, could be indicative of natural attenuation.

To support remediation by natural attenuation at most sites, the investigator will have to show that contaminant mass is being destroyed via biodegradation. This is done using either or both of the second or third lines of evidence. The second line of evidence relies on chemical and physical data to show that contaminant mass is being destroyed via biodegradation, not just diluted. The second line of evidence is divided into two components:

- Using chemical analytical data in mass balance calculations to show that decreases in contaminant and electron acceptor and donor concentrations can be directly correlated to increases in metabolic end products and daughter compounds. This evidence can be used to show that electron acceptor and donor concentrations in ground water are sufficient to facilitate degradation of dissolved contaminants. Solute fate-and-transport models can be used to aid mass balance calculations and to collate information on degradation.
- Using measured concentrations of contaminants and/or biologically recalcitrant tracers in conjunction with aquifer hydrogeologic parameters, such as seepage velocity and dilution, to show that a reduction in contaminant mass is occurring at the site and to calculate biodegradation rate constants.

The third line of evidence, microbiological laboratory data, can be used to provide additional evidence that indigenous biota are capable of degrading site contaminants at a particular rate. Because it is necessary to show that biodegradation is occurring and to obtain biodegradation rate constants, the most useful type of microbiological laboratory data is the microcosm study.

This paper presents a technical course of action that allows converging lines of evidence to be used to scientifically document the occurrence and quantify the rates of natural attenuation. Ideally, the first two lines of evidence

should be used in the natural attenuation demonstration. To further document natural attenuation, or at sites with complex hydrogeology, obtaining a field-scale biodegradation rate may not be possible; in this case, microbiological laboratory data can be used. Such a "weight-of-evidence" approach will greatly increase the likelihood of successfully implementing natural attenuation at sites where natural processes are restoring the environmental quality of ground water.

Collection of an adequate database during the iterative site characterization process is an important step in the documentation of natural attenuation. Site characterization should provide data on the location, nature, and extent of contaminant sources. Contaminant sources generally consist of hydrocarbons present as mobile NAPL (i.e., NAPL occurring at sufficiently high saturations to drain under the influence of gravity into a well) and residual NAPL (i.e., NAPL occurring at immobile, residual saturation that is unable to drain into a well by gravity). Site characterization also should provide information on the location, extent, and concentrations of dissolved contamination; ground-water geochemical data; geologic information on the type and distribution of subsurface materials; and hydrogeologic parameters such as hydraulic conductivity, hydraulic gradients, and potential contaminant migration pathways to human or ecological receptor exposure points.

The data collected during site characterization can be used to simulate the fate and transport of contaminants in the subsurface. Such simulation allows prediction of the future extent and concentrations of the dissolved contaminant plume. Several models can be used to simulate dissolved contaminant transport and attenuation. The natural attenuation modeling effort has three primary objectives: 1) to predict the future extent and concentration of a dissolved contaminant plume by simulating the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the potential for downgradient receptors to be exposed to contaminant concentrations that exceed regulatory or risk-based levels intended to be protective of human health and the environment; and 3) to provide technical support for the natural attenuation remedial option at postmodeling regulatory negotiations to help design a more accurate verification and monitoring strategy and to help identify early source removal strategies.

Upon completion of the fate-and-transport modeling effort, model predictions can be used in an exposure pathways analysis. If natural attenuation is sufficient to mitigate risks to potential receptors, the proponent of natural attenuation has a reasonable basis for negotiating this option with regulators. The exposure pathways analysis allows the proponent to show that potential exposure pathways to receptors will not be completed.

The material presented herein was prepared through the joint effort of the AFCEE Technology Transfer Division; the Bioremediation Research Team at EPA's National Risk Management Research Laboratory in Ada, Oklahoma (NRMRL), Subsurface Protection and Remediation Division; and Parsons Engineering Science, Inc. (Parsons ES). This compilation is designed to facilitate implementation of natural attenuation at chlorinated aliphatic hydrocarbon-contaminated sites owned by the U.S. Air Force and other U.S. Department of Defense agencies, the U.S. Department of Energy, and public interests.

Overview of Chlorinated Aliphatic Hydrocarbon Biodegradation

Because biodegradation is the most important process acting to remove contaminants from ground water, an accurate estimate of the potential for natural biodegradation is important to obtain when determining whether ground-water contamination presents a substantial threat to human health and the environment. This information also will be useful when selecting the remedial alternative that will be most cost-effective in eliminating or abating these threats should natural attenuation alone not prove to be sufficient.

Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons and chlorinated solvents (3-23). Whereas fuel hydrocarbons are biodegraded through use as a primary substrate (electron donor), chlorinated aliphatic hydrocarbons may undergo biodegradation through three different pathways: through use as an electron acceptor, through use as an electron donor, or through co-metabolism, where degradation of the chlorinated organic is fortuitous and there is no benefit to the microorganism. At a given site, one or all of these processes may be operating, although at many sites the use of chlorinated aliphatic hydrocarbons as electron acceptors appears to be most important under natural conditions. In general, but in this case especially, biodegradation of chlorinated aliphatic hydrocarbons will be an electron-donor-limited process. Conversely, biodegradation of fuel hydrocarbons is an electron-acceptor-limited process.

In a pristine aquifer, native organic carbon is used as an electron donor, and dissolved oxygen (DO) is used first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbon) is present, it also will be used as an electron donor. After the DO is consumed, anaerobic microorganisms typically use additional electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how chlorinated aliphatic hydrocarbon biodegradation

is occurring. In addition, because chlorinated aliphatic hydrocarbons may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds can provide evidence of the mechanisms of biodegradation working at a site. As with BTEX, the driving force behind oxidation-reduction reactions resulting in chlorinated aliphatic hydrocarbon degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in chlorinated aliphatic hydrocarbon reduction and oxidation do not proceed abiotically. Microorganisms are capable of carrying out the reactions, but they will facilitate only those oxidation-reduction reactions that have a net yield of energy.

Mechanisms of Chlorinated Aliphatic Hydrocarbon Biodegradation

Electron Acceptor Reactions (Reductive Dechlorination)

The most important process for the natural biodegradation of the more highly chlorinated solvents is reductive dechlorination. During this process, the chlorinated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chlorine atom is removed and replaced with a hydrogen atom. In general, reductive dechlorination occurs by sequential dechlorination from perchloroethene to trichloroethene to dichloroethene to vinyl chloride to ethene. Depending on environmental conditions, this sequence may be interrupted, with other processes then acting on the products. During reductive dechlorination, all three isomers of dichloroethene can theoretically be produced; however, Bouwer (24) reports that under the influence of biodegradation, *cis*-1,2-dichloroethene is a more common intermediate than *trans*-1,2-dichloroethene, and that 1,1-dichloroethene is the least prevalent intermediate of the three dichloroethene isomers. Reductive dechlorination of chlorinated solvent compounds is associated with an accumulation of daughter products and an increase in the concentration of chloride ions.

Reductive dechlorination affects each of the chlorinated ethenes differently. Of these compounds, perchloroethene is the most susceptible to reductive dechlorination because it is the most oxidized. Conversely, vinyl chloride is the least susceptible to reductive dechlorination because it is the least oxidized of these compounds. The rate of reductive dechlorination also has been observed to decrease as the degree of chlorination decreases (24, 25). Murray and Richardson (26) have postulated that this rate decrease may explain the accumulation of vinyl chloride in perchloroethene and trichloroethene plumes that are undergoing reductive dechlorination.

Reductive dechlorination has been demonstrated under nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of chlorinated aliphatic hydrocarbons, occur under methanogenic conditions (24). Because chlorinated aliphatic hydrocarbon compounds are used as electron acceptors during reductive dechlorination, there must be an appropriate source of carbon in order for microbial growth to occur (24). Potential carbon sources include natural organic matter, fuel hydrocarbons, or other organic compounds such as those found in landfill leachate.

Electron Donor Reactions

Murray and Richardson (26) write that microorganisms are generally believed to be incapable of growth using trichloroethene and perchloroethene as a primary substrate (i.e., electron donor). Under aerobic and some anaerobic conditions, the less-oxidized chlorinated aliphatic hydrocarbons (e.g., vinyl chloride) can be used as the primary substrate in biologically mediated redox reactions (22). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded chlorinated aliphatic hydrocarbon. This is the process by which fuel hydrocarbons are biodegraded.

In contrast to reactions in which the chlorinated aliphatic hydrocarbon is used as an electron acceptor, only the least oxidized chlorinated aliphatic hydrocarbons can be used as electron donors in biologically mediated redox reactions. McCarty and Semprini (22) describe investigations in which vinyl chloride and 1,2-dichloroethane were shown to serve as primary substrates under aerobic conditions. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (27) show evidence of mineralization of vinyl chloride under iron-reducing conditions so long as there is sufficient bioavailable iron(III). Aerobic metabolism of vinyl chloride may be characterized by a loss of vinyl chloride mass and a decreasing molar ratio of vinyl chloride to other chlorinated aliphatic hydrocarbon compounds.

Co-metabolism

When a chlorinated aliphatic hydrocarbon is biodegraded via co-metabolism, the degradation is catalyzed by an enzyme or cofactor that is fortuitously produced by the organisms for other purposes. The organism receives no known benefit from the degradation of the chlorinated aliphatic hydrocarbon; in fact, the co-metabolic degradation of the chlorinated aliphatic hydrocarbon may be harmful to the microorganism responsible for the production of the enzyme or cofactor (22).

Co-metabolism is best documented in aerobic environments, although it could occur under anaerobic conditions. It has been reported that under aerobic conditions

chlorinated ethenes, with the exception of perchloroethene, are susceptible to co-metabolic degradation (22, 23, 26). Vogel (23) further elaborates that the co-metabolism rate increases as the degree of dechlorination decreases. During co-metabolism, trichloroethene is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, trichloroethene does not enhance the degradation of BTEX or other carbon sources, nor will its co-metabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources.

Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of biologically available organic carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being used. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and this anthropogenic carbon drives reductive dechlorination. When evaluating natural attenuation of a plume exhibiting Type 1, behavior the following questions must be answered:

1. Is the electron donor supply adequate to allow microbial reduction of the chlorinated organic compounds? In other words, will the microorganisms "strangle" before they "starve"—will they run out of chlorinated aliphatic hydrocarbons (electron acceptors) before they run out of electron donors?
2. What is the role of competing electron acceptors (e.g., DO, nitrate, iron(III), and sulfate)?
3. Is vinyl chloride oxidized, or is it reduced?

Type 1 behavior results in the rapid and extensive degradation of the highly chlorinated solvents such as perchloroethene, trichloroethene, and dichloroethene.

Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high concentrations of biologically available native organic carbon. This natural carbon source drives reductive dechlorination (i.e., is the primary substrate for microorganism growth). When evaluating natural attenuation of a Type 2 chlorinated solvent plume, the same questions as those posed for Type 1 behavior must be answered. Type 2 behavior generally results in slower biodegradation of the highly chlorinated solvents than Type 1 behavior, but under the right

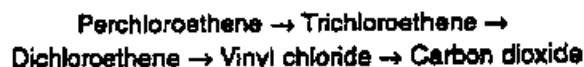
conditions (e.g., areas with high natural organic carbon contents) this type of behavior also can result in rapid degradation of these compounds.

Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low concentrations of native and/or anthropogenic carbon and by DO concentrations greater than 1.0 milligrams per liter. Under these aerobic conditions, reductive dechlorination will not occur; thus, there is no removal of perchloroethene, trichloroethene, and dichloroethene. The most significant natural attenuation mechanisms for these compounds is advection, dispersion, and sorption. However, vinyl chloride can be rapidly oxidized under these conditions.

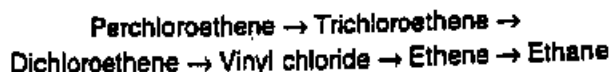
Mixed Behavior

A single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of chlorinated aliphatic hydrocarbon plumes. For example, Wiedemeier et al. (28) describe a plume at Plattsburgh Air Force Base, New York, that exhibits Type 1 behavior in the source area and Type 3 behavior downgradient from the source. The most fortuitous scenario involves a plume in which perchloroethene, trichloroethene, and dichloroethene are reductively dechlorinated (Type 1 or 2 behavior), then vinyl chloride is oxidized (Type 3 behavior) either aerobically or via iron reduction. Vinyl chloride is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in a plume that exhibits this type of mixed behavior:



The trichloroethene, dichloroethene, and vinyl chloride may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. Vinyl chloride is removed from the system much faster under these conditions than it is under vinyl chloride-reducing conditions.

A less desirable scenario—but one in which all contaminants may be entirely biodegraded—involves a plume in which all chlorinated aliphatic hydrocarbons are reductively dechlorinated via Type 1 or Type 2 behavior. Vinyl chloride is reduced to ethene, which may be further reduced to ethane or methane. The following sequence of reactions occurs in this type of plume:



This sequence has been investigated by Freedman and Gossett (13). In this type of plume, vinyl chloride degrades more slowly than trichloroethene and thus tends to accumulate.

Protocol for Quantifying Natural Attenuation During the Remedial Investigation Process

The primary objective of the natural attenuation investigation is to show that natural processes of contaminant degradation will reduce contaminant concentrations in ground water to below risk-based corrective action or regulatory levels before potential receptor exposure pathways are completed. This requires a projection of the potential extent and concentration of the contaminant plume in time and space. The projection should be based on historic variations in, and the current extent and concentrations of, the contaminant plume, as well as the measured rates of contaminant attenuation. Because of the inherent uncertainty associated with such predictions, the investigator must provide sufficient evidence to demonstrate that the mechanisms of natural attenuation will reduce contaminant concentrations to acceptable levels before potential receptors are reached. This requires the use of conservative solute fate-and-transport model input parameters and numerous sensitivity analyses so that consideration is given to all plausible contaminant migration scenarios. When possible, both historical data and modeling should be used to provide information that collectively and consistently supports the natural reduction and removal of the dissolved contaminant plume.

Figure 1 outlines the steps involved in the natural attenuation demonstration. This figure also shows the important regulatory decision points in the process of implementing natural attenuation. Predicting the fate of a contaminant plume requires the quantification of solute transport and transformation processes. Quantification of contaminant migration and attenuation rates and successful implementation of the natural attenuation remedial option requires completion of the following steps:

1. Review available site data, and develop a preliminary conceptual model.
2. Screen the site, and assess the potential for natural attenuation.
3. Collect additional site characterization data to support natural attenuation, as required.
4. Refine the conceptual model, complete premodeling calculations, and document indicators of natural attenuation.
5. Simulate natural attenuation using analytical or numerical solute fate-and-transport models that allow incorporation of a biodegradation term, as necessary.

6. Identify potential receptors, and conduct an exposure-pathway analysis.
7. Evaluate the practicability and potential efficiency of supplemental source removal options.
8. If natural attenuation with or without source removal is acceptable, prepare a long-term monitoring plan.
9. Present findings to regulatory agencies, and obtain approval for remediation by natural attenuation.

Review Available Site Data, and Develop a Preliminary Conceptual Model

Existing site characterization data should be reviewed and used to develop a conceptual model for the site. The preliminary conceptual model will help identify any shortcomings in the data and will allow placement of additional data collection points in the most scientifically advantageous and cost-effective manner. A conceptual model is a three-dimensional representation of the ground-water flow and solute transport system based on available geological, biological, geochemical, hydrological, climatological, and analytical data for the site. This type of conceptual model differs from the conceptual site models that risk assessors commonly use that qualitatively consider the location of contaminant sources, release mechanisms, transport pathways, exposure points, and receptors. The ground-water system conceptual model, however, facilitates identification of these risk-assessment elements for the exposure pathways analysis. After development, the conceptual model can be used to help determine optimal placement of additional data collection points (as necessary) to aid in the natural attenuation investigation and to develop the solute fate-and-transport model.

Contracting and management controls must be flexible enough to allow for the potential for revisions to the conceptual model and thus the data collection effort. In cases where few or no site-specific data are available, all future site characterization activities should be designed to collect the data necessary to screen the site to determine the potential for remediation by natural attenuation. The additional costs incurred by such data collection are greatly outweighed by the cost savings that will be realized if natural attenuation is selected. Moreover, most of the data collected in support of natural attenuation can be used to design and support other remedial measures.

Table 1 contains the soil and ground-water analytical protocol for natural attenuation of chlorinated aliphatic hydrocarbons and/or fuel hydrocarbons. Table 1A lists a standard set of methods, while Table 1B lists methods that are under development and/or consideration. Any plan to collect additional ground-water and soil quality data should include targeting the analytes listed in Table 1A, and possibly Table 1B.

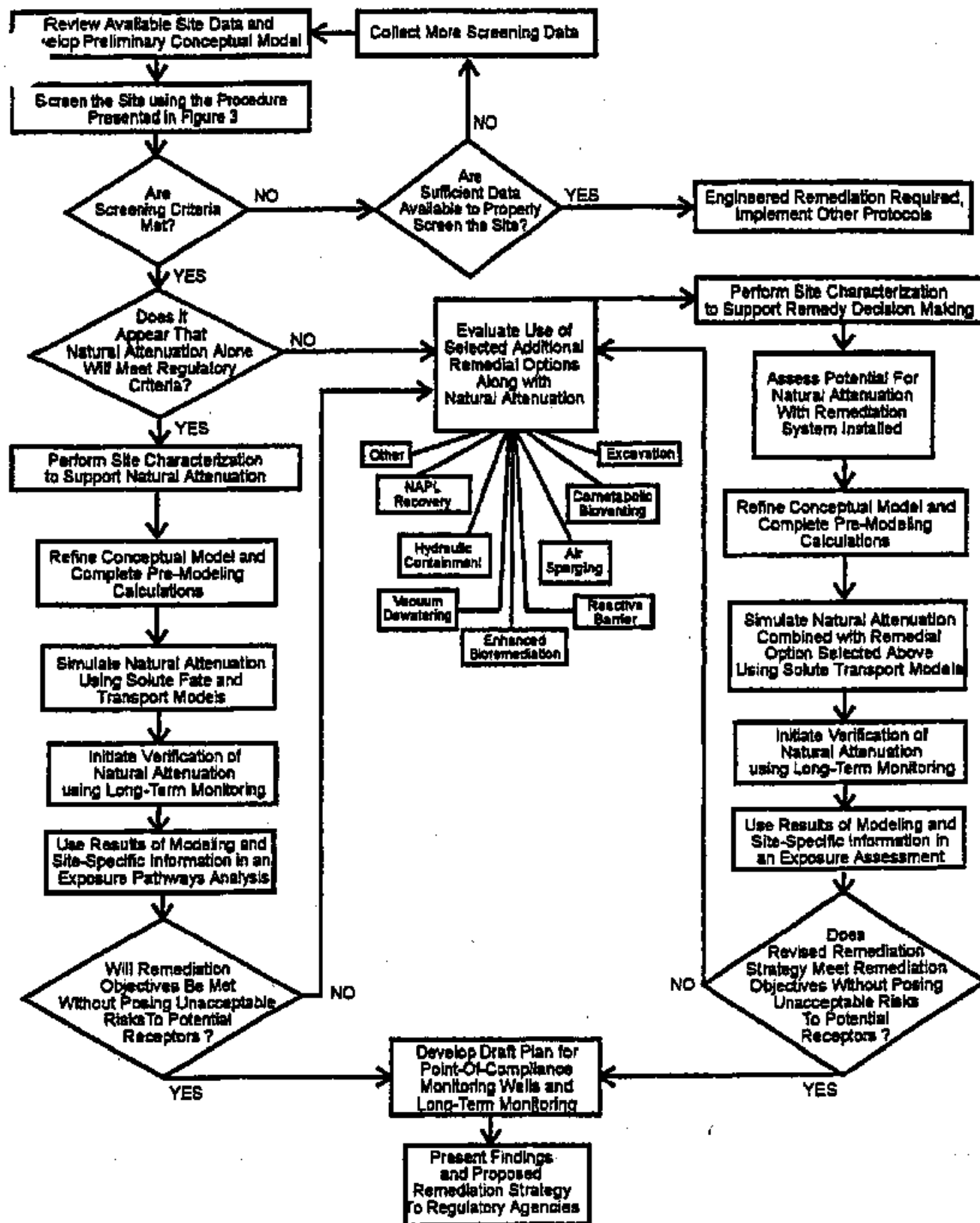


Figure 1. Natural attenuation of chlorinated solvents flow chart.

Table 1A. Soil and Ground-Water Analytical Protocol^a

Matrix	Analysis	Method/Reference ^{b,c}	Comments ^{d,e}	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Volatile organic compounds	SW8260A	Handbook method modified for field extraction of soil using methanol	Useful for determining the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW8060, modified for soil samples	Procedure must be accurate over the range of 0.5 to 15% TOC	The amount of TOC in the aquifer matrix influences contaminant migration and biodegradation	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil gas	O ₂ , CO ₂	Field soil gas analyzer		Useful for determining bioactivity in the vadose zone	At initial sampling and respiration testing	Reusable 3-L Tedlar bags	Field
Soil gas	Fuel and chlorinated volatile organic compounds	EPA Method TO-14		Useful for determining the distribution of chlorinated and BTEX compounds in soil	At initial sampling	1-L Summa canister	Fixed-base
Water	Volatile organic compounds	SW8260A	Handbook method; analysis may be extended to higher molecular-weight alkyl benzenes	Method of analysis for BTEX and chlorinated solvents/byproducts	Each sampling round	Collect water samples in a 40-mL volatile organic analysis vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional; intended for diesel and other heavy oils)	Gas chromatography/mass spectroscopy Method SW8270B; high-performance liquid chromatography Method SW8310	Analysis needed only when required for regulatory compliance	PAHs are components of fuel and are typically analyzed for regulatory compliance	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Oxygen	DO meter	Refer to Method A4500 for a comparable laboratory procedure	Concentrations less than 1 mg/L generally indicate an anaerobic pathway	Each sampling round	Measure DO on site using a flow-through cell	Field
Water	Nitrate	Ion chromatography Method E300; anion method	Method E300 is a handbook method; also provides chloride data	Substrate for microbial respiration if oxygen is depleted	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H ₂ SO ₄ to pH less than 2; cool to 4°C	Fixed-base
Water	Iron(II) (Fe ²⁺)	Colorimetric HACH Method 8146	Filter if turbid	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese	Each sampling round	Collect 100 mL of water in a glass container	Field

Table 1A: Soil and Ground-Water Analytical Protocol^a (Continued)

Matrix	Analysis	Method/Reference ^{b,c}	Comments ^{d,e}	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Sulfate (SO ₄ -2)	Ion chromatography Method E300 or HACH Method 8051	Method E300 is a handbook method, HACH Method 8051 is a colorimetric method; use one or the other	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	E300 = Fixed-base HACH Method 8051 = Field
Water	Methane, ethane, and ethene	Kempbell et al. (35) or SW3810, modified	Method published by EPA researchers	The presence of CH ₄ suggests biodegradation of organic carbon via methanogenesis; ethane and ethene are produced during reductive dechlorination	Each sampling round	Collect water samples in 60 mL glass serum bottles with butyl gray/Teflon-lined caps; add H ₂ SO ₄ to pH less than 2; cool to 4°C	Fixed-base
Water	Alkalinity	HACH alkalinity test kit Model AL AP MG-L	Phenolphthalein method	Water quality parameter used to measure the buffering capacity of ground water; can be used to estimate the amount of CO ₂ produced during biodegradation	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential	A2580B	Measurements made with electrodes, results are displayed on a meter, protect samples from exposure to oxygen; report results against a silver/silver chloride reference electrode	The oxidation-reduction potential of ground water influences and is influenced by the nature of the biologically mediated degradation of contaminants; the oxidation-reduction potential of ground water may range from more than 800 mV to less than -400 mV	Each sampling round	Collect 100 to 250 mL of water in a glass container	Field
Water	pH	Field probe with direct reading meter	Field	Aerobic and anaerobic processes are pH-sensitive	Each sampling round	Collect 100 to 250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter	Field only	Well development	Each sampling round	Not applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	Water quality parameter used as a marker to verify that site samples are obtained from the same ground-water system	Each sampling round	Collect 100 to 250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl ⁻ C	Ion chromatography Method E300; Method SW9050 may also be used	Final product of chlorinated solvent reduction; can be used to estimate dilution in calculation of rate constant	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base

Table 1A. Soil and Ground-Water Analytical Protocol^a (Continued)

Matrix	Analysis	Method/Reference ^{b,c}	Comments ^d	Data Use	Recommended Frequency of Analysis	Sample Volume, Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Chloride (optional; see data use)	HACH chloride test kit Model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Total organic carbon	SW9050	Laboratory	Used to classify plumes and to determine whether anaerobic metabolism of chlorinated solvents is possible in the absence of anthropogenic carbon	Each sampling round	Collect 100 mL of water in a glass container, cool	Laboratory

^a Analyses other than those listed in this table may be required for regulatory compliance.

^b "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical and Chemical Methods* (29).

^c "E" refers to *Methods for Chemical Analysis of Water and Wastes* (30).

^d "HACH" refers to the Hach Company catalog (31).

^e "A" refers to *Standard Methods for the Examination of Water and Wastewater* (32).

^f "Handbook" refers to the AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS) (33).

^g "Protocol" refers to the AFCEE Environmental Chemistry Function Installation Restoration Program Analytical Protocols (34).

Table 1B. Soil and Ground-Water Analytical Protocol: Special Analyses Under Development and/or Consideration^{a,b}

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Container, Preservation	Field or Fixed-Base Laboratory
Soil	Biologically available iron(II)	Under development	HCl extraction followed by quantification of released iron(II)	To predict the possible extent of iron reduction in an aquifer	One round of sampling in five borings, five cores from each boring	Collect minimum 1-inch diameter core samples into a plastic liner; cap and prevent oxidation	Laboratory
Water	Nutritional quality of native organic matter	Under development	Spectrophotometric method	To determine the extent of reductive dechlorination allowed by the supply of electron donor	One round of sampling in two to five wells	Collect 1,000 mL in an amber glass container	Laboratory
Water	Hydrogen (H ₂)	Equilibration with gas in the field; determined with a reducing gas detector	Specialized analysis	To determine the terminal electron accepting process; predicts the possibility for reductive dechlorination	One round of sampling	Sampling at well head requires the production of 100 mL per minute of water for 30 minutes	Field
Water	Oxygenates (including methyl- <i>tert</i> -butyl ether, ethers, acetic acid, methanol, and acetone)	SW8260/8015 ^c	Laboratory	Contaminant or electron donors for dechlorination of solvents	At least one sampling round or as determined by regulators	Collect 1 L of water in a glass container; preserve with HCl	Laboratory

^a Analyses other than those listed in this table may be required for regulatory compliance.

^b Site characterization should not be delayed if these methods are unavailable.

^c "SW" refers to *Test Methods for Evaluating Solid Waste, Physical and Chemical Methods* (29).

Screen the Site, and Assess the Potential for Natural Attenuation

After reviewing available site data and developing a preliminary conceptual model, an assessment of the potential for natural attenuation must be made. As stated previously, existing data can be useful in determining whether natural attenuation will be sufficient to prevent a dissolved contaminant plume from completing exposure pathways, or from reaching a predetermined point of compliance, in concentrations above applicable regulatory or risk-based corrective action standards. Determining the likelihood of exposure pathway completion is an important component of the natural attenuation investigation. This is achieved by estimating the migration and future extent of the plume based on contaminant properties, including volatility, sorptive properties, and biodegradability; aquifer properties, including hydraulic gradient, hydraulic conductivity, porosity, and total organic carbon (TOC) content; and the location of the plume and contaminant source relative to potential receptors (i.e., the distance between the leading edge of the plume and the potential receptor exposure points). These parameters (estimated or actual) are used in this section to make a preliminary assessment of the effectiveness of natural attenuation in reducing contaminant concentrations.

If, after completing the steps outlined in this section, it appears that natural attenuation will be a significant factor in contaminant removal, detailed site characterization activities in support of this remedial option should be performed. If exposure pathways have already been completed and contaminant concentrations exceed regulatory levels, or if such completion is likely, other remedial measures should be considered, possibly in conjunction with natural attenuation. Even so, the collection of data in support of the natural attenuation option can be integrated into a comprehensive remedial plan and may help reduce the cost and duration of other remedial measures, such as intensive source removal operations or pump-and-treat technologies. For example, dissolved iron concentrations can have a profound influence on the design of pump-and-treat systems.

Based on the experience of the authors, in an estimated 80 percent of fuel hydrocarbon spills at federal facilities, natural attenuation alone will be protective of human health and the environment. For spills of chlorinated aliphatic hydrocarbons at federal facilities, however, natural attenuation alone will be protective of human health and the environment in an estimated 20 percent of the cases. With this in mind, it is easy to understand why an accurate assessment of the potential for natural biodegradation of chlorinated compounds should be made before investing in a detailed study of natural attenuation. The screening process presented in this section is outlined in Figure 2. This approach should

allow the investigator to determine whether natural attenuation is likely to be a viable remedial alternative before additional time and money are expended. The data required to make the preliminary assessment of natural attenuation can also be used to aid the design of an engineered remedial solution, should the screening process suggest that natural attenuation alone is not feasible.

The following information is required for the screening process:

- The chemical and geochemical data presented in Table 2 for a minimum of six samples. Figure 3 shows the approximate location of these data collection points. If other contaminants are suspected, then data on the concentration and distribution of these compounds also should be obtained.
- Locations of source(s) and receptor(s).
- An estimate of the contaminant transport velocity and direction of ground-water flow.

Once these data have been collected, the screening process can be undertaken. The following steps summarize the screening process:

1. Determine whether biodegradation is occurring using geochemical data. If biodegradation is occurring, proceed to Step 2. If it is not, assess the amount and types of data available. If data are insufficient to determine whether biodegradation is occurring, collect supplemental data.
2. Determine ground-water flow and solute transport parameters. Hydraulic conductivity and porosity may be estimated, but the ground-water gradient and flow direction may not. The investigator should use the highest hydraulic conductivity measured at the site during the preliminary screening because solute plumes tend to follow the path of least resistance (i.e., highest hydraulic conductivity). This will give the "worst case" estimate of solute migration over a given period.
3. Locate sources and receptor exposure points.
4. Estimate the biodegradation rate constant. Biodegradation rate constants can be estimated using a conservative tracer found commingled with the contaminant plume, as described by Wiedemeier et al. (36). When dealing with a plume that contains only chlorinated solvents, this procedure will have to be modified to use chloride as a tracer. Rate constants derived from microcosm studies can also be used. If it is not possible to estimate the biodegradation rate using these procedures, then use a range of accepted literature values for biodegradation of the contaminants of concern.

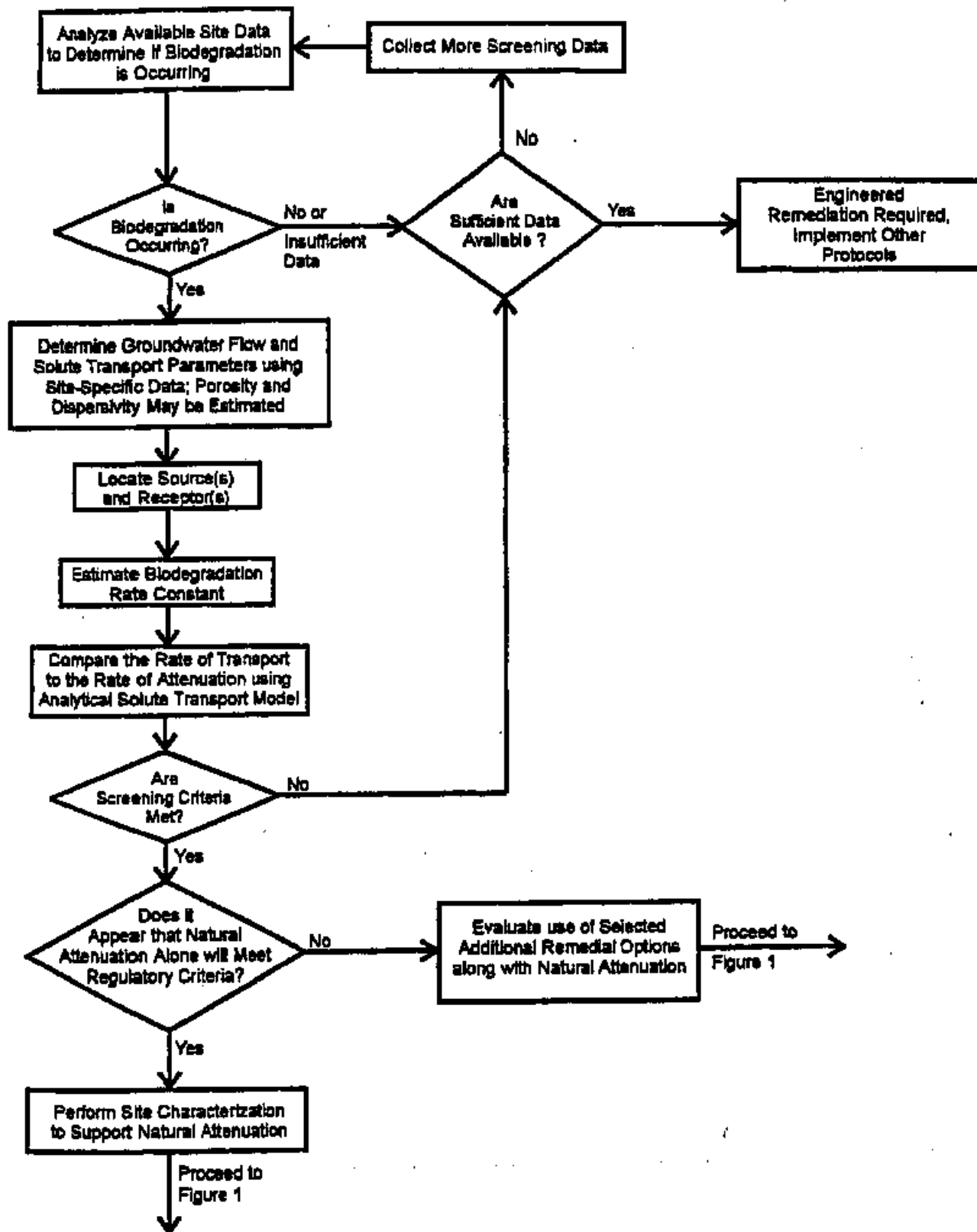
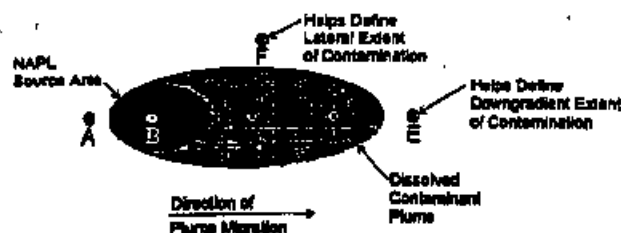


Figure 2. Initial screening process flow chart.

Table 2. Analytical Parameters and Weighting for Preliminary Screening

Analyte	Concentration in Most Contaminated Zone	Interpretation	Points Awarded
Argon ^a	< 0.5 mg/L	Tolerated; suppresses reductive dechlorination at higher concentrations	3
Oxygen ^a	> 1 mg/L	Vinyl chloride may be oxidized aerobically, but reductive dechlorination will not occur	-3
Nitrate ^a	< 1 mg/L	May compete with reductive pathway at higher concentrations	2
Iron (II) ^a	> 1 mg/L	Reductive pathway possible	3
Sulfate ^a	< 20 mg/L	May compete with reductive pathway at higher concentrations	2
Sulfide ^a	> 1 mg/L	Reductive pathway possible	3
Methane ^a	> 0.1 mg/L	Ultimate reductive daughter product	2
	> 1	Vinyl chloride accumulates	3
	< 1	Vinyl chloride oxidizes	
Oxidation reduction potential ^a	< 50 mV against Ag/AgCl	Reductive pathway possible	< 50 mV = 1 < -100 mV = 2
pH ^a	5 < pH < 9	Tolerated range for reductive pathway	
DOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature ^a	> 20°C	At T > 20°C, biochemical process is accelerated	1
Carbon dioxide	> 2x background	Ultimate oxidative daughter product	1
Alkalinity	> 2x background	Results from interaction of carbon dioxide with aquifer minerals	1
Chloride ^a	> 2x background	Daughter product of organic chlorine; compare chloride in plume to background conditions	2
Hydrogen	> 1 nM	Reductive pathway possible; vinyl chloride may accumulate	3
Hydrogen	< 1 nM	Vinyl chloride oxidized	
Volatile fatty acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2
BTEX ^a	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2
Perchloroethene ^a		Material released	
Trichloroethene ^a		Material released or daughter product of perchloroethene	2 ^b
Dichloroethene ^a		Material released or daughter product of trichloroethene; If amount of <i>cis</i> -1,2-dichloroethene is greater than 80% of total dichloroethene, it is likely a daughter product of trichloroethene	2 ^b
Vinyl chloride ^a		Material released or daughter product of dichloroethenes	2 ^b
Ethene/Ethane	< 0.1 mg/L	Daughter product of vinyl chloride/ethene	> 0.01 mg/L = 2 > 0.1 = 3
Chloroethane ^a		Daughter product of vinyl chloride under reducing conditions	2
1,1,1-Trichloroethane ^a		Material released	
1,1-dichloroethane ^a		Daughter product of trichloroethene or chemical reaction of 1,1,1-trichloroethane	

^a Required analysis.^b Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).



LEGEND

● Required Data Collection Point
○ Not To Be Sampled

Figure 3. Data collection points required for screening.

5. Compare the rate of transport to the rate of attenuation, using analytical solutions or a screening model such as BIOSCREEN.

6. Determine whether the screening criteria are met.

Each of these steps is described in detail below.

Step 1: Determine Whether Biodegradation Is Occurring

The first step in the screening process is to sample at least six wells that are representative of the contaminant flow system and to analyze the samples for the parameters listed in Table 2. Samples should be taken 1) from the most contaminated portion of the aquifer (generally in the area where NAPL currently is present or was present in the past); 2) downgradient from the NAPL source area but still in the dissolved contaminant plume; 3) downgradient from the dissolved contaminant plume; and 4) from upgradient and lateral locations that are not affected by the plume.

Samples collected in the NAPL source area allow determination of the dominant terminal electron-accepting processes at the site. In conjunction with samples collected in the NAPL source zone, samples collected in the dissolved plume downgradient from the NAPL source zone allow the investigator to determine whether the plume is degrading with distance along the flow path and what the distribution of electron acceptors and donors and metabolic byproducts might be along the flow path. The sample collected downgradient from the dissolved plume aids in plume delineation and allows the investigator to determine whether metabolic byproducts are present in an area of ground water that has been remediated. The upgradient and lateral samples allow delineation of the plume and indicate background concentrations of the electron acceptors and donors.

After these samples have been analyzed for the parameters listed in Table 2, the investigator should analyze the data to determine whether biodegradation is occurring. The right-hand column of Table 2 contains

scoring values that can be used for this task. For example, if the DO concentration in the area of the plume with the highest contaminant concentration is less than 0.5 milligrams per liter, this parameter is awarded 3 points. Table 3 summarizes the range of possible scores and gives an interpretation for each score. If the site scores a total of 15 or more points, biodegradation is probably occurring, and the investigator can proceed to Step 2. This method relies on the fact that biodegradation will cause predictable changes in ground-water chemistry.

Table 3. Interpretation of Points Awarded During Screening Step 1

Score	Interpretation
0 to 5	Inadequate evidence for biodegradation of chlorinated organics
6 to 14	Limited evidence for biodegradation of chlorinated organics
15 to 20	Adequate evidence for biodegradation of chlorinated organics
> 20	Strong evidence for biodegradation of chlorinated organics

Consider the following two examples. Example 1 contains data for a site with strong evidence that reductive dechlorination is occurring. Example 2 contains data for a site with strong evidence that reductive dechlorination is not occurring.

Example 1. Strong Evidence for Biodegradation of Chlorinated Organics

Analyte	Concentration in Most Contaminated Zone	Points Awarded
DO	0.1 mg/L	3
Nitrate	0.3 mg/L	2
Iron(II)	10 mg/L	3
Sulfate	2 mg/L	2
Methane	5 mg/L	3
Oxidation-reduction potential	-190 mV	2
Chloride	3x background	2
Perchloroethene (released)	1,000 µg/L	0
Trichloroethene (none released)	1,200 µg/L	2
cis-1,2-Dichloroethene (none released)	500 µg/L	2
Vinyl chloride (none released)	50 µg/L	2
Total points awarded		23

In this example, the investigator can infer that biodegradation is occurring and may proceed to Step 2.

Example 2. Biodegradation of Chlorinated Organics Unlikely

Analyte	Concentration in Most Contaminated Zone	Points Awarded
DO	3 mg/L	-3
Nitrate	0.3 mg/L	2
Iron(II)	Not detected	0
Sulfate	10 mg/L	2
Methane	ND	0
Oxidation-reduction potential	100 mV	0
Chloride	Background	0
Trichloroethene (released)	1,200 µg/L	0
cis-1,2-Dichloroethene	Not detected	0
Vinyl chloride	ND	0
Total points awarded		1

In this example, the investigator can infer that biodegradation is probably not occurring or is occurring too slowly as a viable remedial option. In this case, the investigator cannot proceed to Step 2 and will likely have to implement an engineered remediation system.

Step 2: Determine Ground-Water Flow and Solute Transport Parameters

After biodegradation has been shown to be occurring, it is important to quantify ground-water flow and solute transport parameters. This will make it possible to use a solute transport model to quantitatively estimate the concentration of the plume and its direction and rate of travel. To use an analytical model, it is necessary to know the hydraulic gradient and hydraulic conductivity for the site and to have estimates of the porosity and dispersivity. The coefficient of retardation also is helpful to know. Quantification of these parameters is discussed by Wiedemeier et al. (1).

To make modeling as accurate as possible, the investigator must have site-specific hydraulic gradient and hydraulic conductivity data. To determine the ground-water flow and solute transport direction, the site must have at least three accurately surveyed wells. The porosity and dispersivity are generally estimated using accepted literature values for the types of sediments found at the site.

If the investigator does not have TOC data for soil, the coefficient of retardation can be estimated; however,

assuming that the solute transport and ground-water velocities are the same may be more conservative.

Step 3: Locate Sources and Receptor Exposure Points

To determine the length of flow for the predictive modeling conducted in Step 5, it is important to know the distance between the source of contamination, the downgradient end of the dissolved plume, and any potential downgradient or cross-gradient receptors.

Step 4: Estimate the Biodegradation Rate Constant

Biodegradation is the most important process that degrades contaminants in the subsurface; therefore, the biodegradation rate is one of the most important model input parameters. Biodegradation of chlorinated aliphatic hydrocarbons can commonly be represented as a first-order rate constant. Site-specific biodegradation rates generally are best to use. Calculation of site-specific biodegradation rates is discussed by Wiedemeier et al. (1, 36, 37). If determining site-specific biodegradation rates is impossible, then literature values for the biodegradation rate of the contaminant of interest must be used. It is generally best to start with the average value and then to vary the model input to predict "best case" and "worst case" scenarios. Estimated biodegradation rates can be used only after biodegradation has been shown to be occurring (see Step 1).

Step 5: Compare the Rate of Transport to the Rate of Attenuation

At this early stage in the natural attenuation demonstration, comparison of the rate of solute transport to the rate of attenuation is best accomplished using an analytical model. Several analytical models are available, but the BIOSCREEN model is probably the simplest to use. This model is nonproprietary and is available from the Robert S. Kerr Laboratory's home page on the Internet (www.epa.gov/ada/kerrlab.html). The BIOSCREEN model is based on Domenico's solution to the advection-dispersion equation (38), and allows use of either a first-order biodegradation rate or an instantaneous reaction between contaminants and electron acceptors to simulate the effects of biodegradation. To model transport of chlorinated aliphatic hydrocarbons using BIOSCREEN, only the first-order decay rate option should be used. BIOCHLOR, a similar model, is under development by the Technology Transfer Division of AFCEE. This model will likely use the same analytical solution as BIOSCREEN but will be geared towards evaluating transport of chlorinated compounds under the influence of biodegradation.

The primary purpose of comparing the rate of transport with the rate of attenuation is to determine whether the

residence time along the flow path is adequate to be protective of human health and the environment (i.e., to qualitatively estimate whether the contaminant is attenuating at a rate fast enough to allow degradation of the contaminant to acceptable concentrations before receptors are reached). It is important to perform a sensitivity analysis to help evaluate the confidence in the preliminary screening modeling effort. If modeling shows that receptors may not be exposed to contaminants at concentrations above risk-based corrective action criteria, then the screening criteria are met, and the investigator can proceed with the natural attenuation feasibility study.

Step 6: Determine Whether the Screening Criteria Are Met

Before proceeding with the full-scale natural attenuation feasibility study, the investigator should ensure that the answers to all of the following criteria are "yes":

- Has the plume moved a distance less than expected, based on the known (or estimated) time since the contaminant release and the contaminant velocity, as calculated from site-specific measurements of hydraulic conductivity and hydraulic gradient, as well as estimates of effective porosity and contaminant retardation?
- Is it likely that the contaminant mass is attenuating at rates sufficient to be protective of human health and the environment at a point of discharge to a sensitive environmental receptor?
- Is the plume going to attenuate to concentrations less than risk-based corrective action guidelines before reaching potential receptors?

Collect Additional Site Characterization Data To Support Natural Attenuation, As Required

Detailed site characterization is necessary to document the potential for natural attenuation. Review of existing site characterization data is particularly useful before initiating site characterization activities. Such review should allow identification of data gaps and guide the most effective placement of additional data collection points.

There are two goals during the site characterization phase of a natural attenuation investigation. The first is to collect the data needed to determine whether natural mechanisms of contaminant attenuation are occurring at rates sufficient to protect human health and the environment. The second is to provide sufficient site-specific data to allow prediction of the future extent and concentration of a contaminant plume through solute fate-and-transport modeling. Because the burden of proof for natural attenuation is on the proponent, detailed site characterization is required to achieve these goals and to support this remedial option. Adequate site characterization in support of natural attenuation requires that the following site-specific parameters be determined:

- The extent and type of soil and ground-water contamination.
- The location and extent of contaminant source area(s) (i.e., areas containing mobile or residual NAPL).
- The potential for a continuing source due to leaking tanks or pipelines.
- Aquifer geochemical parameters.
- Regional hydrogeology, including drinking water aquifers and regional confining units.
- Local and site-specific hydrogeology, including local drinking water aquifers; location of industrial, agricultural, and domestic water wells; patterns of aquifer use (current and future); lithology; site stratigraphy, including identification of transmissive and nontransmissive units; grain-size distribution (sand versus silt versus clay); aquifer hydraulic conductivity; ground-water hydraulic information; preferential flow paths; locations and types of surface water bodies; and areas of local ground-water recharge and discharge.
- Identification of potential exposure pathways and receptors.

The following sections describe the methodologies that should be implemented to allow successful site characterization in support of natural attenuation. Additional information can be obtained from Wiedemeier et al. (1, 37).

Soil Characterization

To adequately define the subsurface hydrogeologic system and to determine the amount and three-dimensional distribution of mobile and residual NAPL that can act as a continuing source of ground-water contamination, extensive soil characterization must be completed. Depending on the status of the site, this work may have been completed during previous remedial investigation activities. The results of soils characterization will be used as input into a solute fate-and-transport model to help define a contaminant source term and to support the natural attenuation investigation.

The purpose of soil sampling is to determine the subsurface distribution of hydrostratigraphic units and the distribution of mobile and residual NAPL. These objectives can be achieved through the use of conventional soil borings or direct-push methods (e.g., Geoprobe or cone penetrometer testing). All soil samples should be collected, described, analyzed, and disposed of in accordance with local, state, and federal guidance. Wiedemeier et al. (1) present suggested procedures for soil sample collection. These procedures may require modification to comply with local, state, and federal regulations or to accommodate site-specific conditions.

The analytical protocol to be used for soil sample analysis is presented in Table 1. This analytical protocol

includes all of the parameters necessary to document natural attenuation, including the effects of sorption and biodegradation. Knowledge of the location, distribution, concentration, and total mass of contaminants of regulatory concern sorbed to soils or present as residual and/or mobile NAPL is required to calculate contaminant partitioning from NAPL into ground water. Knowledge of the TOC content of the aquifer matrix is important for sorption and solute-retardation calculations. TOC samples should be collected from a background location in the stratigraphic horizon(s) where most contaminant transport is expected to occur. Oxygen and carbon dioxide measurements of soil gas can be used to find areas in the unsaturated zone where biodegradation is occurring. Knowledge of the distribution of contaminants in soil gas can be used as a cost-effective way to estimate the extent of soil contamination.

Ground-Water Characterization

To adequately determine the amount and three-dimensional distribution of dissolved contamination and to document the occurrence of natural attenuation, ground-water samples must be collected and analyzed. Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of ground water in the affected area. By measuring these changes, documentation and quantitative evaluation of natural attenuation's importance at a site are possible.

Ground-water sampling is conducted to determine the concentrations and distribution of contaminants, daughter products, and ground-water geochemical parameters. Ground-water samples may be obtained from monitoring wells or with point-source sampling devices such as a Geoprobe, Hydropunch, or cone penetrometer. All ground-water samples should be collected in accordance with local, state, and federal guidelines. Wiedemeier et al. (1) suggest procedures for ground-water sample collection. These procedures may need to be modified to comply with local, state, and federal regulations or to accommodate site-specific conditions.

The analytical protocol for ground-water sample analysis is presented in Table 1. This analytical protocol includes all of the parameters necessary to document natural attenuation, including the effects of sorption and biodegradation. Data obtained from the analysis of ground water for these analytes is used to scientifically document natural attenuation and can be used as input into a solute fate-and-transport model. The following paragraphs describe each ground-water analytical parameter and the use of each analyte in the natural attenuation demonstration.

Volatile organic compound analysis (by Method W8260a) is used to determine the types, concentrations, and distributions of contaminants and daughter

products in the aquifer. DO is the electron acceptor most thermodynamically favored by microbes for the biodegradation of organic carbon, whether natural or anthropogenic. Reductive dechlorination will not occur, however, if DO concentrations are above approximately 0.5 milligrams per liter. During aerobic biodegradation of a substrate, DO concentrations decrease because of the microbial oxygen demand. After DO depletion, anaerobic microbes will use nitrate as an electron acceptor, followed by iron(III), then sulfate, and finally carbon dioxide (methanogenesis). Each sequential reaction drives the oxidation-reduction potential of the ground water further into the realm where reductive dechlorination can occur. The oxidation-reduction potential range of sulfate reduction and methanogenesis is optimal, but reductive dechlorination may occur under nitrate- and iron(III)-reducing conditions as well. Because reductive dechlorination works best in the sulfate-reduction and methanogenesis oxidation-reduction potential range, competitive exclusion between microbial sulfate reducers, methanogens, and reductive dechlorinators can occur.

After DO has been depleted in the microbiological treatment zone, nitrate may be used as an electron acceptor for anaerobic biodegradation via denitrification. In some cases iron(III) is used as an electron acceptor during anaerobic biodegradation of electron donors. During this process, iron(III) is reduced to iron(II), which may be soluble in water. Iron(II) concentrations can thus be used as an indicator of anaerobic degradation of fuel compounds. After DO, nitrate, and bioavailable iron(III) have been depleted in the microbiological treatment zone, sulfate may be used as an electron acceptor for anaerobic biodegradation. This process is termed sulfate reduction and results in the production of sulfide. During methanogenesis (an anaerobic biodegradation process), carbon dioxide (or acetate) is used as an electron acceptor, and methane is produced. Methanogenesis generally occurs after oxygen, nitrate, bioavailable iron(III), and sulfate have been depleted in the treatment zone. The presence of methane in ground water is indicative of strongly reducing conditions. Because methane is not present in fuel, the presence of methane in ground water above background concentrations in contact with fuels is indicative of microbial degradation of fuel hydrocarbons.

The total alkalinity of a ground-water system is indicative of a water's capacity to neutralize acid. Alkalinity is defined as "the net concentration of strong base in excess of strong acid with a pure CO₂-water system as the point of reference" (39). Alkalinity results from the presence of hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium, or ammonia. These species result from the dissolution of rock (especially carbonate rocks), the transfer of carbon dioxide from the atmosphere, and the

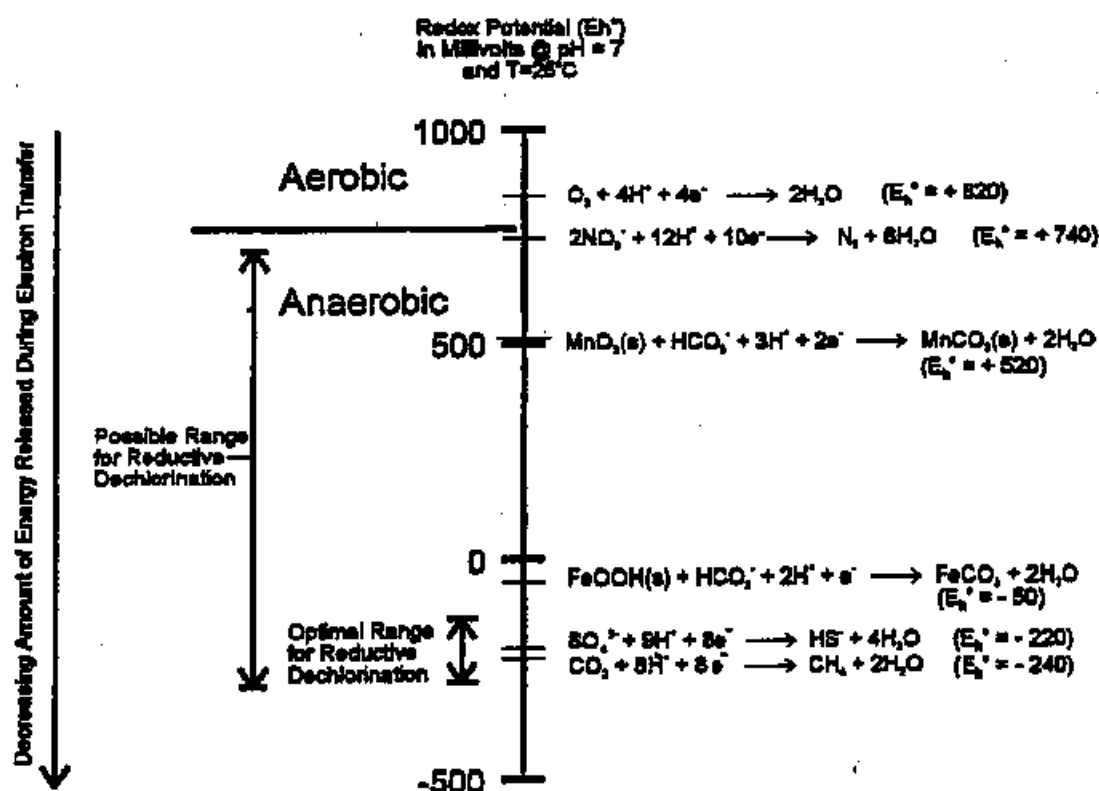
respiration of microorganisms. Alkalinity is important in the maintenance of ground-water pH because it buffers the ground-water system against acids generated during both aerobic and anaerobic biodegradation.

In general, areas contaminated by fuel hydrocarbons exhibit a total alkalinity that is higher than that seen in background areas. This is expected because the microbially mediated reactions causing biodegradation of fuel hydrocarbons cause an increase in the total alkalinity in the system. Changes in alkalinity are most pronounced during aerobic respiration, denitrification, iron reduction, and sulfate reduction, and are less pronounced during methanogenesis (40). In addition, Willey et al. (41) show that short-chain aliphatic acid ions produced during biodegradation of fuel hydrocarbons can contribute to alkalinity in ground water.

The oxidation-reduction potential of ground water is a measure of electron activity and an indicator of the relative tendency of a solution to accept or transfer electrons. Redox reactions in ground water containing organic compounds (natural or anthropogenic) are usually biologically mediated; therefore, the oxidation-reduction

potential of a ground-water system depends on and influences rates of biodegradation. Knowledge of the oxidation-reduction potential of ground water also is important because some biological processes operate only within a prescribed range of redox conditions. The oxidation-reduction potential of ground water generally ranges from -400 to 800 millivolts (mV). Figure 4 shows the typical redox conditions for ground water when different electron acceptors are used.

Oxidation-reduction potential can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. Mapping the oxidation-reduction potential of the ground water while in the field helps the field scientist to determine the approximate location of the contaminant plume. To perform this task, it is important to have at least one redox measurement (preferably more) from a well located upgradient from the plume. Oxidation-reduction potential measurements should be taken during well purging and immediately before and after sample acquisition using a direct-reading meter. Because most well purging techniques can allow aeration of collected ground-water samples (which can affect oxidation-reduction



Modified From Bouwer (1994)

Figure 4. Redox potentials for various electron acceptors.

potential measurements), it is important to minimize potential aeration.

Dissolved hydrogen concentrations can be used to delineate the dominant terminal electron-accepting processes in an aquifer. Because of the difficulty in obtaining hydrogen analyses commercially, this parameter should be considered optional at this time. Table 4 presents the range of hydrogen concentrations for a given terminal electron-accepting process. Much research has been done on the topic of using hydrogen measurements to delineate terminal electron-accepting processes (42-44). Because the efficiency of reductive dechlorination differs for methanogenic, sulfate-reducing, iron(III)-reducing, or denitrifying conditions, it is helpful to have hydrogen concentrations to help delineate redox conditions when evaluating the potential for natural attenuation of chlorinated ethenes in ground-water systems. Collection and analysis of ground-water samples for dissolved hydrogen content is not yet commonplace or standardized, however, and requires a relatively expensive field laboratory setup.

Table 4. Range of Hydrogen Concentrations for a Given Terminal Electron-Accepting Process

Terminal Electron-Accepting Process	Hydrogen Concentration (nanomoles per liter)
Denitrification	< 0.1
Iron(III) reduction	0.2 to 0.8
Sulfate reduction	1 to 4
Methanogenesis	> 5

Because the pH, temperature, and conductivity of a ground-water sample can change significantly shortly following sample acquisition, these parameters must be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for DO and redox analyses. The measurements should be made in a clean glass container separate from those intended for laboratory analysis, and the measured values should be recorded in the ground-water sampling record.

The pH of ground water has an effect on the presence and activity of microbial populations in the ground water. This is especially true for methanogens. Microbes capable of degrading chlorinated aliphatic hydrocarbons and petroleum hydrocarbon compounds generally prefer pH values varying from 6 to 8 standard units. Ground-water temperature directly affects the solubility of oxygen and other geochemical species. The solubility of DO is temperature dependent, being more soluble in cold water than in warm water. Ground-water temperature also affects the metabolic activity of bacteria. Rates of hydrocarbon

biodegradation roughly double for every 10°C increase in temperature ("Q₁₀ rule") over the temperature range between 5°C and 25°C. Ground-water temperatures less than about 5°C tend to inhibit biodegradation, and slow rates of biodegradation are generally observed in such waters.

Conductivity is a measure of the ability of a solution to conduct electricity. The conductivity of ground water is directly related to the concentration of ions in solution; conductivity increases as ion concentration increases. Conductivity measurements are used to ensure that ground water samples collected at a site are representative of the water in the saturated zone containing the dissolved contamination. If the conductivities of samples taken from different sampling points are radically different, the waters may be from different hydrogeologic zones.

Elemental chlorine is the most abundant of the halogens. Although chlorine can occur in oxidation states ranging from Cl⁻ to Cl⁺⁷, the chloride form (Cl⁻) is the only form of major significance in natural waters (45). Chloride forms ion pairs or complex ions with some of the cations present in natural waters, but these complexes are not strong enough to be of significance in the chemistry of fresh water (45). The chemical behavior of chloride is neutral. Chloride ions generally do not enter into oxidation-reduction reactions, form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces, and play few vital biochemical roles (45). Thus, physical processes control the migration of chloride ions in the subsurface.

Kaufman and Orlow (46) conducted tracer experiments in ground water and found that chloride moved through most of the soils tested more conservatively (i.e., with less retardation and loss) than any of the other tracers tested. During biodegradation of chlorinated hydrocarbons dissolved in ground water, chloride is released into the ground water. This results in chloride concentrations in the ground water of the contaminant plume that are elevated relative to background concentrations. Because of the neutral chemical behavior of chloride, it can be used as a conservative tracer to estimate biodegradation rates using methods similar to those discussed by Wiedemeier et al. (36).

Field Measurement of Aquifer Hydraulic Parameters

The properties of an aquifer that have the greatest impact on contaminant fate and transport include hydraulic conductivity, hydraulic gradient, porosity, and dispersivity. Estimating hydraulic conductivity and gradient in the field is fairly straightforward, but obtaining field-scale information on porosity and dispersivity can be difficult.

Therefore, most investigators rely on field data for hydraulic conductivity and hydraulic gradient and on literature values for porosity and dispersivity for the types of sediments present at the site. Methods for field measurement of aquifer hydraulic parameters are described by Wiedemeier et al. (1, 37).

Microbiological Laboratory Data

Microcosm studies are used to show that the microorganisms necessary for biodegradation are present and to help quantify rates of biodegradation. If properly designed, implemented, and interpreted, microcosm studies can provide very convincing documentation of the occurrence of biodegradation. Such studies are the only "line of evidence" that allows an unequivocal mass balance determination based on the biodegradation of environmental contaminants. The results of a well-designed microcosm study will be easy for decision-makers with nontechnical backgrounds to interpret. Results of such studies are strongly influenced by the nature of the geological material submitted for study, the physical properties of the microcosm, the sampling strategy, and the duration of the study. Because microcosm studies are time-consuming and expensive, they should be undertaken only at sites where there is considerable skepticism concerning the biodegradation of contaminants.

Biodegradation rate constants determined by microcosm studies often are much greater than rates achieved in the field. Microcosms are most appropriate as indicators of the potential for natural bioremediation and to prove that losses are biological, but it may be inappropriate to use them to generate rate constants. The preferable method of contaminant biodegradation rate-constant determination is in situ field measurement. The collection of material for the microcosm study, the procedures used to set up and analyze the microcosm, and the interpretation of the results of the microcosm study are presented by Wiedemeier et al. (1).

Refine the Conceptual Model, Complete Premodeling Calculations, and Document Indicators of Natural Attenuation

Site investigation data should first be used to refine the conceptual model and quantify ground-water flow, sorption, dilution, and biodegradation. The results of these calculations are used to scientifically document the occurrence and rates of natural attenuation and to help simulate natural attenuation over time. Because the burden of proof is on the proponent, all available data must be integrated in such a way that the evidence is sufficient to support the conclusion that natural attenuation is occurring.

Conceptual Model Refinement

Conceptual model refinement involves integrating newly gathered site characterization data to refine the prelimi-

nary conceptual model that was developed based on previously existing site-specific data. During conceptual model refinement, all available site-specific data should be integrated to develop an accurate three-dimensional representation of the hydrogeologic and contaminant transport system. This conceptual model can then be used for contaminant fate-and-transport modeling. Conceptual model refinement consists of several steps, including preparation of geologic logs, hydrogeologic sections, potentiometric surface/water table maps, contaminant contour (isopleth) maps, and electron acceptor and metabolic byproduct contour (isopleth) maps. Refinement of the conceptual model is described by Wiedemeier et al. (1).

Premodeling Calculations

Several calculations must be made prior to implementation of the solute fate-and-transport model. These calculations include sorption and retardation calculations, NAPL/water-partitioning calculations, ground-water flow velocity calculations, and biodegradation rate-constant calculations. Each of these calculations is discussed in the following sections. Most of the specifics of each calculation are presented in the fuel hydrocarbon natural attenuation technical protocol by Wiedemeier et al. (1), and all will be presented in the protocol incorporating chlorinated aliphatic hydrocarbon attenuation (37).

Biodegradation Rate Constant Calculations

Biodegradation rate constants are necessary to simulate accurately the fate and transport of contaminants dissolved in ground water. In many cases, biodegradation of contaminants can be approximated using first-order kinetics. To calculate first-order biodegradation rate constants, the apparent degradation rate must be normalized for the effects of dilution and volatilization. Two methods for determining first-order rate constants are described by Wiedemeier et al. (38). One method involves the use of a biologically recalcitrant compound found in the dissolved contaminant plume that can be used as a conservative tracer. The other method, proposed by Buscheck and Aicantar (47) involves interpretation of a steady-state contaminant plume and is based on the one-dimensional steady-state analytical solution to the advection-dispersion equation presented by Bear (48). The first-order biodegradation rate constants for chlorinated aliphatic hydrocarbons are also presented (J. Wilson et al., this volume).

Simulate Natural Attenuation Using Solute Fate-and-Transport Models

Simulating natural attenuation using a solute fate-and-transport model allows prediction of the migration and attenuation of the contaminant plume through time. Natural attenuation modeling is a tool that allows site-specific

data to be used to predict the fate and transport of solutes under governing physical, chemical, and biological processes. Hence, the results of the modeling effort not in themselves sufficient proof that natural attenuation is occurring at a given site. The results of the modeling effort are only as good as the original data input into the model; therefore, an investment in thorough site characterization will improve the validity of the modeling results. In some cases, straightforward analytical models of contaminant attenuation are adequate to simulate natural attenuation.

Several well-documented and widely accepted solute fate-and-transport models are available for simulating the fate-and-transport of contaminants under the influence of advection, dispersion, sorption, and biodegradation. The use of solute fate-and-transport modeling in the natural attenuation investigation is described by Wiedemeier et al. (1).

Identify Potential Receptors, and Conduct an Exposure-Pathway Analysis

After the rates of natural attenuation have been documented and predictions of the future extent and concentrations of the contaminant plume have been made using the appropriate solute fate-and-transport model, the proponent of natural attenuation should combine all available data and information to negotiate for implementation of this remedial option. Supporting the natural attenuation option generally will involve performing a receptor exposure-pathway analysis. This analysis includes identifying potential human and ecological receptors and points of exposure under current and future land and ground-water use scenarios. The results of solute fate-and-transport modeling are central to the exposure pathways analysis. If conservative model input parameters are used, the solute fate-and-transport model should give conservative estimates of contaminant plume migration. From this information, the potential for impacts on human health and the environment from contamination present at the site can be estimated.

Evaluate Supplemental Source Removal Options

Source removal or reduction may be necessary to reduce plume expansion if the exposure-pathway analysis suggests that one or more exposure pathways may be completed before natural attenuation can reduce chemical concentrations below risk-based levels of concern. Further, some regulators may require source removal in conjunction with natural attenuation. Several technologies suitable for source reduction or removal are listed in Figure 1. Other technologies may also be used as dictated by site conditions and local regulatory requirements. The authors' experience indicates that source removal can be very effective at limiting plume migration

and decreasing the remediation time frame, especially at sites where biodegradation is contributing to natural attenuation of a dissolved contaminant plume. The impact of source removal can readily be evaluated by modifying the contaminant source term if a solute fate-and-transport model has been prepared for a site; this will allow for a reevaluation of the exposure-pathway analysis.

Prepare a Long-Term Monitoring Plan

Ground-water flow rates at many Air Force sites studied to date are such that many years will be required before contaminated ground water could potentially reach Base property boundaries. Thus, there frequently is time and space for natural attenuation alone to reduce contaminant concentrations in ground water to acceptable levels. Experience at 40 Air Force sites contaminated with fuel hydrocarbons using the protocol presented by Wiedemeier et al. (1) suggests that many fuel hydrocarbon plumes are relatively stable or are moving very slowly with respect to ground-water flow. This information is complemented by data collected by Lawrence Livermore National Laboratories in a study of over 1,100 leaking underground fuel tank sites performed for the California State Water Resources Control Board (49). These examples demonstrate the efficacy of long-term monitoring to track plume migration and to validate or refine modeling results. There is not a large enough database available at this time to assess the stability of chlorinated solvent plumes, but in the authors' experience chlorinated solvent plumes are likely to migrate further downgradient than fuel hydrocarbon plumes before reaching steady-state equilibrium or before receding.

The long-term monitoring plan consists of locating ground-water monitoring wells and developing a ground-water sampling and analysis strategy. This plan is used to monitor plume migration over time and to verify that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors. The long-term monitoring plan should be developed based on site characterization data, the results of solute fate-and-transport modeling, and the results of the exposure-pathway analysis.

The long-term monitoring plan includes two types of monitoring wells: long-term monitoring wells are intended to determine whether the behavior of the plume is changing; point-of-compliance wells are intended to detect movements of the plume outside the negotiated perimeter of containment, and to trigger an action to manage the risk associated with such expansion. Figure 5 depicts 1) an upgradient well in unaffected ground water, 2) a well in the NAPL source area, 3) a well downgradient of the NAPL source area in a zone of anaerobic treatment, 4) a well in the zone of aerobic treatment, along the periphery of the plume, 5) a well

located downgradient from the plume where contaminant concentrations are below regulatory acceptance levels and soluble electron acceptors are depleted with respect to unaffected ground water, and 6) three point-of-compliance wells.

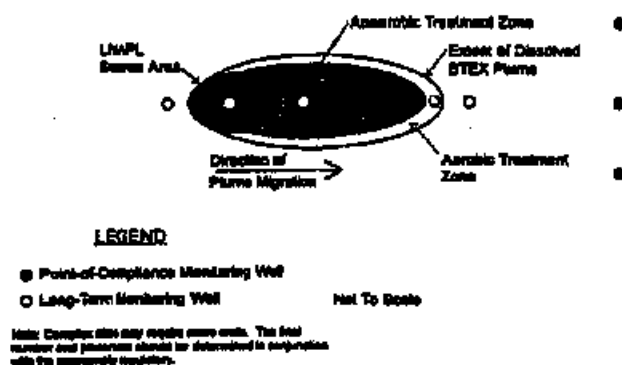


Figure 6. Hypothetical long-term monitoring strategy.

Although the final number and placement of long-term monitoring and point-of-compliance wells is determined through regulatory negotiation, the following guidance is recommended. Locations of long-term monitoring wells are based on the behavior of the plume as revealed during the initial site characterization and on regulatory considerations. Point-of-compliance wells are placed 500 feet downgradient from the leading edge of the plume or the distance traveled by the ground water in 2 years, whichever is greater. If the property line is less than 500 feet downgradient, the point-of-compliance wells are placed near and upgradient from the property line. The final number and location of point-of-compliance monitoring wells also depends on regulatory considerations.

The results of a solute fate-and-transport model can be used to help site the long-term monitoring and point-of-compliance wells. To provide a valid monitoring system, all monitoring wells must be screened in the same hydrogeologic unit as the contaminant plume. This generally requires detailed stratigraphic correlation. To facilitate accurate stratigraphic correlation, detailed visual descriptions of all subsurface materials encountered during borehole drilling should be prepared prior to monitoring-well installation.

A ground-water sampling and analysis plan should be prepared in conjunction with point-of-compliance and long-term monitoring well placement. For long-term monitoring wells, ground-water analyses should include volatile organic compounds, DO, nitrate, iron(II), sulfate, and methane. For point-of-compliance wells, ground-water analyses should be limited to determining volatile organic compound and DO concentrations. Any state-specific analytical requirements also should be ad-

ressed in the sampling and analysis plan to ensure that all data required for regulatory decision-making are collected. Water level and LNAPL thickness measurements must be made during each sampling event. Except at sites with very low hydraulic conductivity and gradients, quarterly sampling of long-term monitoring wells is recommended during the first year to help determine the direction of plume migration and to determine baseline data. Based on the results of the first year's sampling, the sampling frequency may be reduced to annual sampling in the quarter showing the greatest extent of the plume. Sampling frequency depends on the final placement of the point-of-compliance monitoring wells and ground-water flow velocity. The final sampling frequency should be determined in collaboration with regulators.

Present Findings to Regulatory Agencies, and Obtain Approval for Remediation by Natural Attenuation

The purpose of regulatory negotiations is to provide scientific documentation that supports natural attenuation as the most appropriate remedial option for a given site. All available site-specific data and information developed during the site characterization, conceptual model development, premodeling calculations, biodegradation rate calculation, ground-water modeling, model documentation, and long-term monitoring plan preparation phases of the natural attenuation investigation should be presented in a consistent and complementary manner at the regulatory negotiations. Of particular interest to the regulators will be proof that natural attenuation is occurring at rates sufficient to meet risk-based corrective action criteria at the point of compliance and to protect human health and the environment. The regulators must be presented with a "weight-of-evidence" argument in support of this remedial option. For this reason, all model assumptions should be conservative, and all available evidence in support of natural attenuation must be presented at the regulatory negotiations.

A comprehensive long-term monitoring and contingency plan also should be presented to demonstrate a commitment to proving the effectiveness of natural attenuation as a remedial option. Because long-term monitoring and contingency plans are very site specific, they should be addressed in the individual reports generated using this protocol.

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